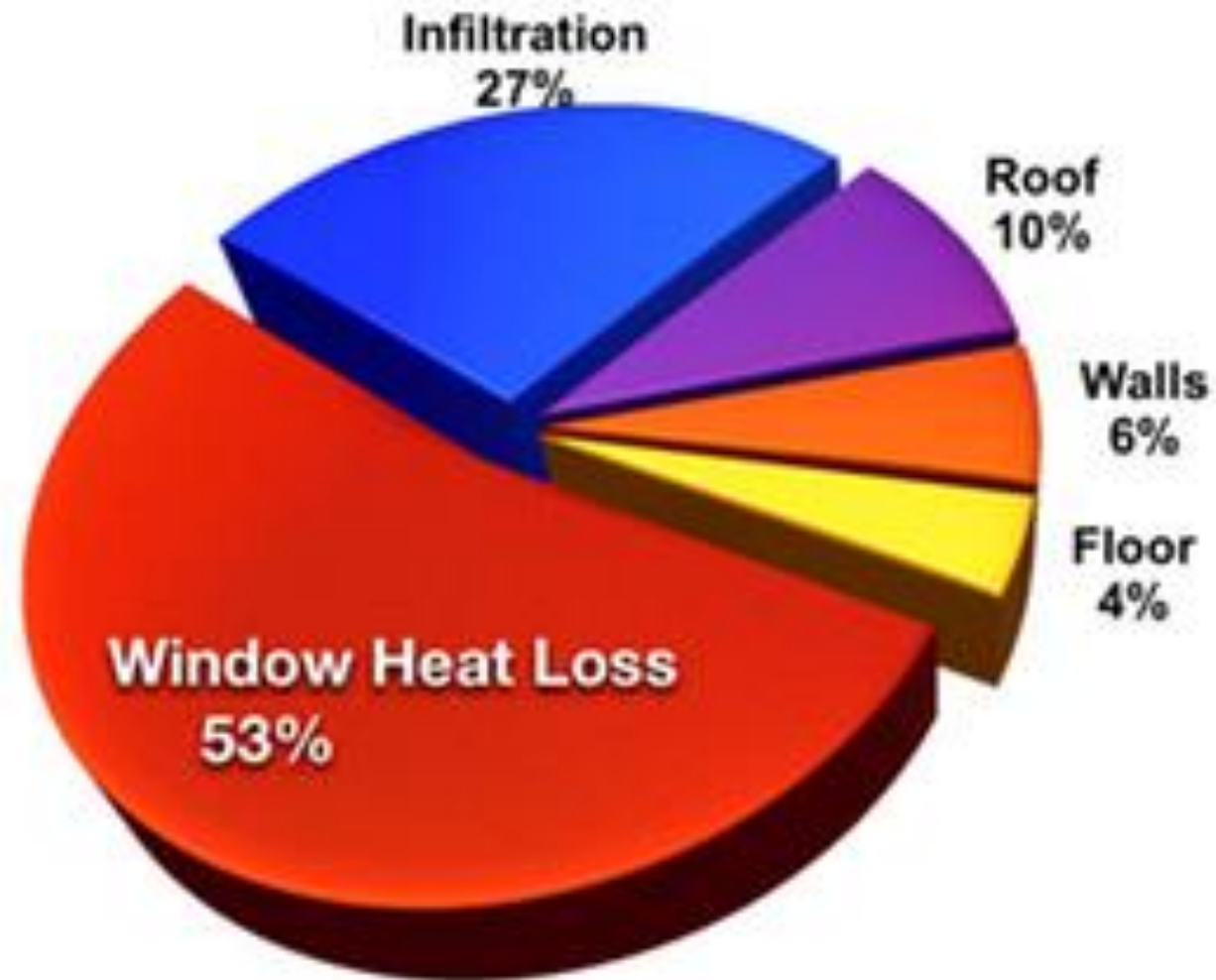


# Integrated System for Economical High Performance Glass Windows & Doors

*Southern Orientation, Strategic Glazing & Zoning, Development of Ultra-energy Efficient Glazing Systems including Thicker More Thermal Resistant Hybrid Frames, State-of-the-Art Thermal Breaks and Foam Installation*

*Providing up to R-16 (U-0.0625) Super Windows & Glass Doors*

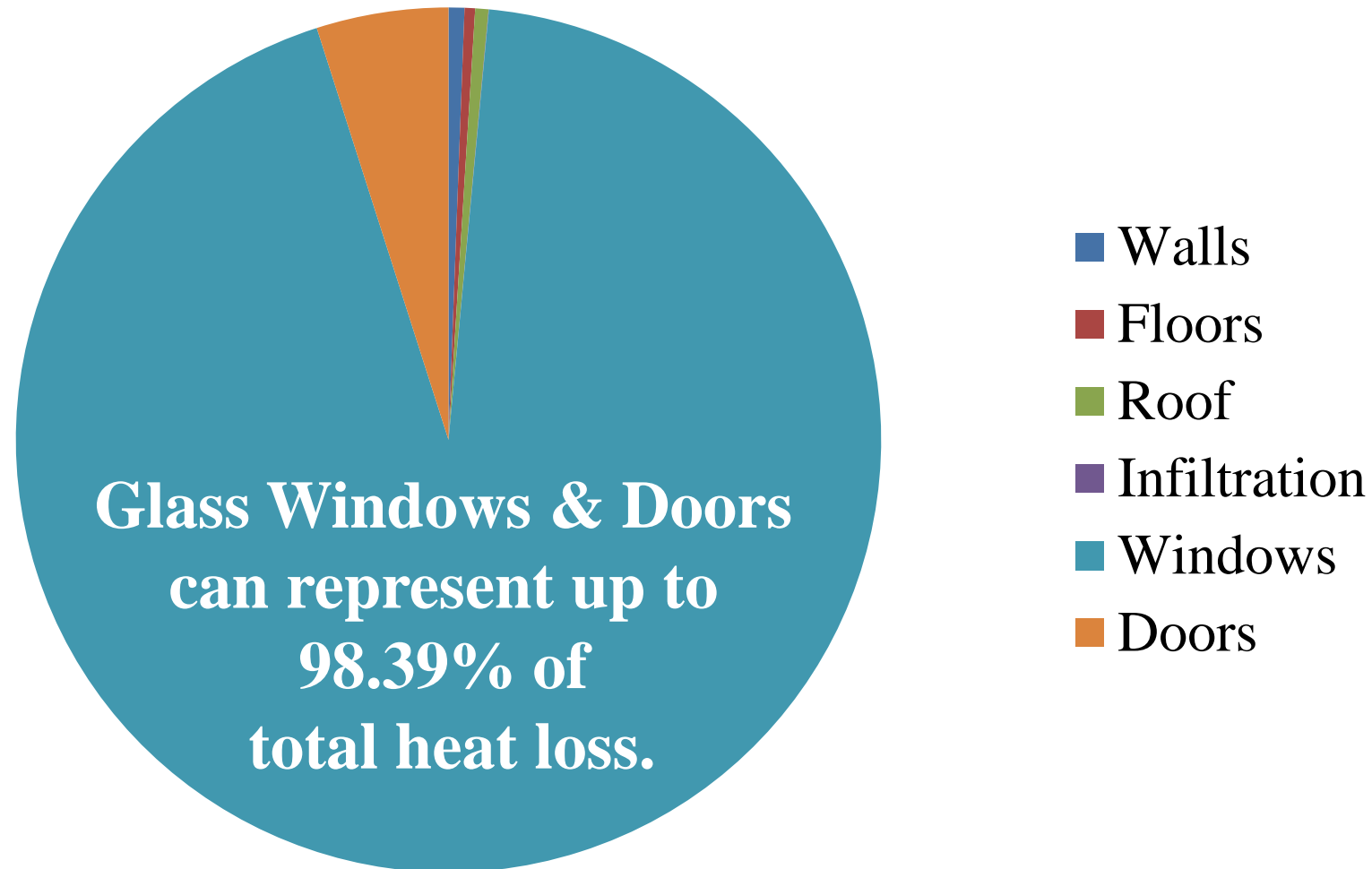
# Conventional Window Heat Loss



# Passive Window Technology

- High performance glazing systems and insulated window frames with state-of-the-art warm edge spacers and thermal breaks can become net-producers of thermal energy during the day.
- Balancing thermal resistance with solar heat gain and thermal mass is critical for passive structures.
- Modern glazing technology, improving thermal resistance of frames, reducing infiltration, and state-of-the-art installation using adequate foam products is required.

# Passive House Glass Windows & Doors Heat Loss



# Zero Energy Windows

- Energy requirements for today's typical efficient window products (i.e. ENERGY STAR™ and passive house products) are significant when compared to the needs of Zero Energy Homes (ZEHs).
- Through the use of whole house energy modeling, typical efficient products were evaluated in five US climates and compared against the requirements for ZEHs.
- Products which meet these needs are defined as a function of climate. In heating dominated climates, windows with U-factors of 0.10 Btu/hr-ft<sup>2</sup>-F (0.57 W/m<sup>2</sup>-K) will become energy neutral.
- In mixed heating/cooling climates a low U-factor is not as significant as the ability to modulate from high SHGCs (heating season) to low SHGCs (cooling season).

(Aresta et al, 2014. Performance Criteria for Residential Zero Energy Windows, Windows and Daylighting Group, LBNL)

# Zero Energy Windows in Northern Climates

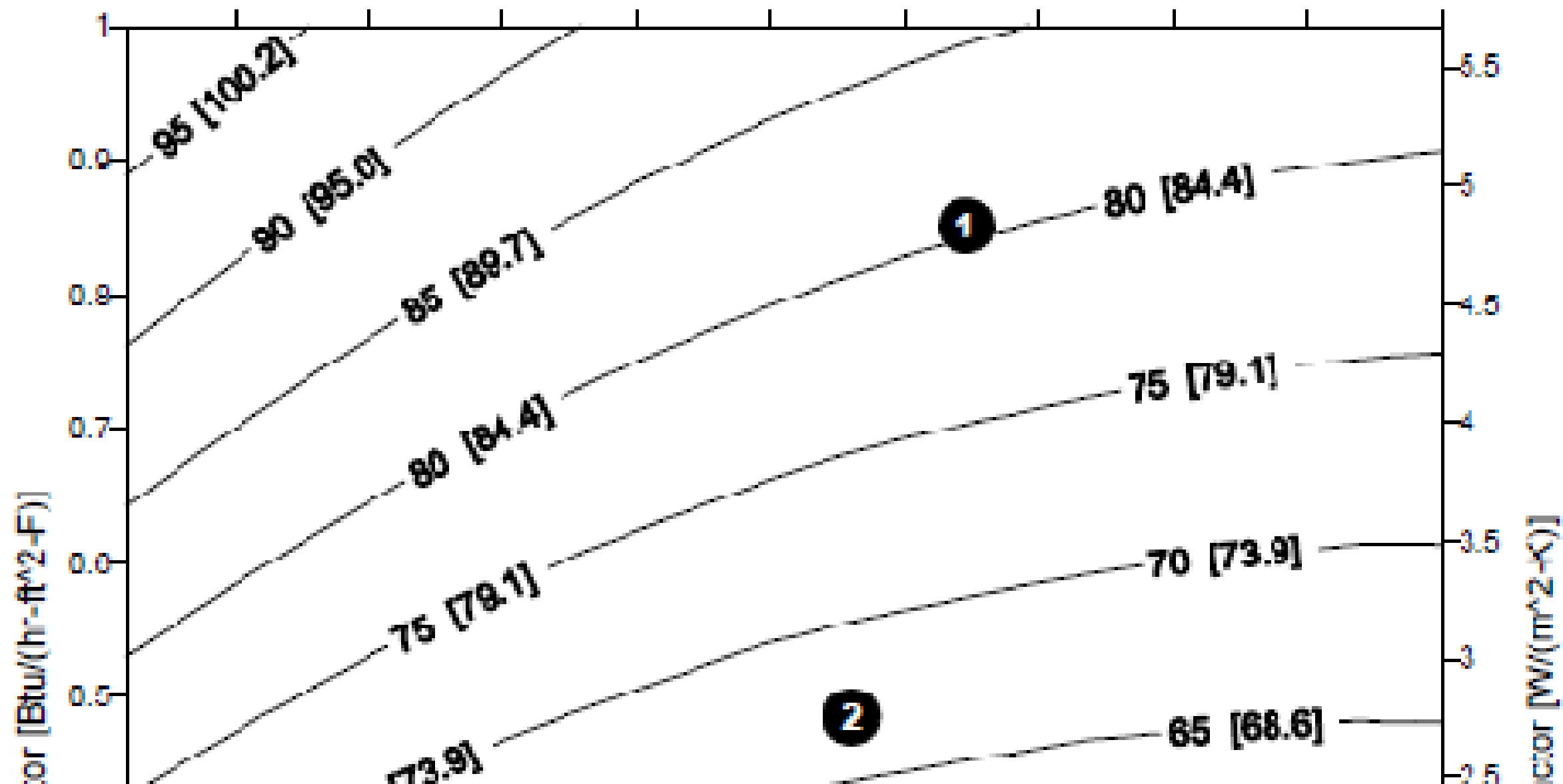
- Our approach to achieving a Zero Energy Window in northern climates is to focus on the development of dynamic windows with a high maximum SHGC (i.e. 0.6). This lessens the need to reduce window U-factors to below 0.2 Btu/hr-ft<sup>2</sup>-F (1.14 W/m<sup>2</sup>-K) for Zero Energy Windows, from an energy perspective.
- However, another significant feature of ZEHs is the downsizing of HVAC systems, which requires that peak load impacts (both winter and summer) be minimized. Such constraints may argue for low U-factor dynamic windows, even if this combination exceeds the requirements for zero energy impacts. This topic of windows for ZEHs and HVAC integration requires additional research.

(Aresta et al, 2014. Performance Criteria for Residential Zero Energy Windows, Windows and Daylighting Group, LBNL)

# Boise, ID ZNE-PHMH Project

- Though we want to showcase state-of-the-art passive house technology, depending on the homeowner's budget we will have the flexibility of designing and building homes that virtually any homeowner can afford.
- Strategic design, orientation, 4' eaves via a 6/12 pitch, and automated exterior shades will allow us to showcase dynamic window systems for zero net energy homes.
- The following illustration for a Salt Lake City residential structure is similar to the environment in Boise, ID where the first ZNE-PHMH will be built. We will be targeting U-0.08 & SHGC 0.5.

# Salt Lake City, UT - Combined Annual Heating and Cooling Energy (contours in MBtu [GJ])



# Innovative Passive Window Technology

- High performance glazing systems, insulated window frames with thermal breaks, and state-of-the-art insulated glass units (IGUs) with warm edge spacers can become net-producers of thermal energy during the day.
- Balancing thermal resistance with solar heat gain and thermal mass is critical for passive structures.
- Modern glazing technology, improving thermal resistance of frames, reducing infiltration, and state-of-the-art installation using adequate foam products is required.
- Automated exterior shades and innovative low-e coatings can minimize heat loss between sunset and sunrise for glazing systems that are designed to optimize solar radiation.

# Zero Energy Windows

- Energy requirements for today's typical efficient window products (i.e. ENERGY STAR™ and passive house products) are significant when compared to the needs of Zero Energy Homes (ZEHs).
- Through the use of whole house energy modeling, typical efficient products were evaluated in five US climates and compared against the requirements for ZEHs.
- Products which meet these needs are defined as a function of climate. In heating dominated climates, windows with U-factors of 0.10 Btu/hr-ft<sup>2</sup>-F (0.57 W/m<sup>2</sup>-K) will become energy neutral.
- In mixed heating/cooling climates a low U-factor is not as significant as the ability to modulate from high SHGCs (heating season) to low SHGCs (cooling season).

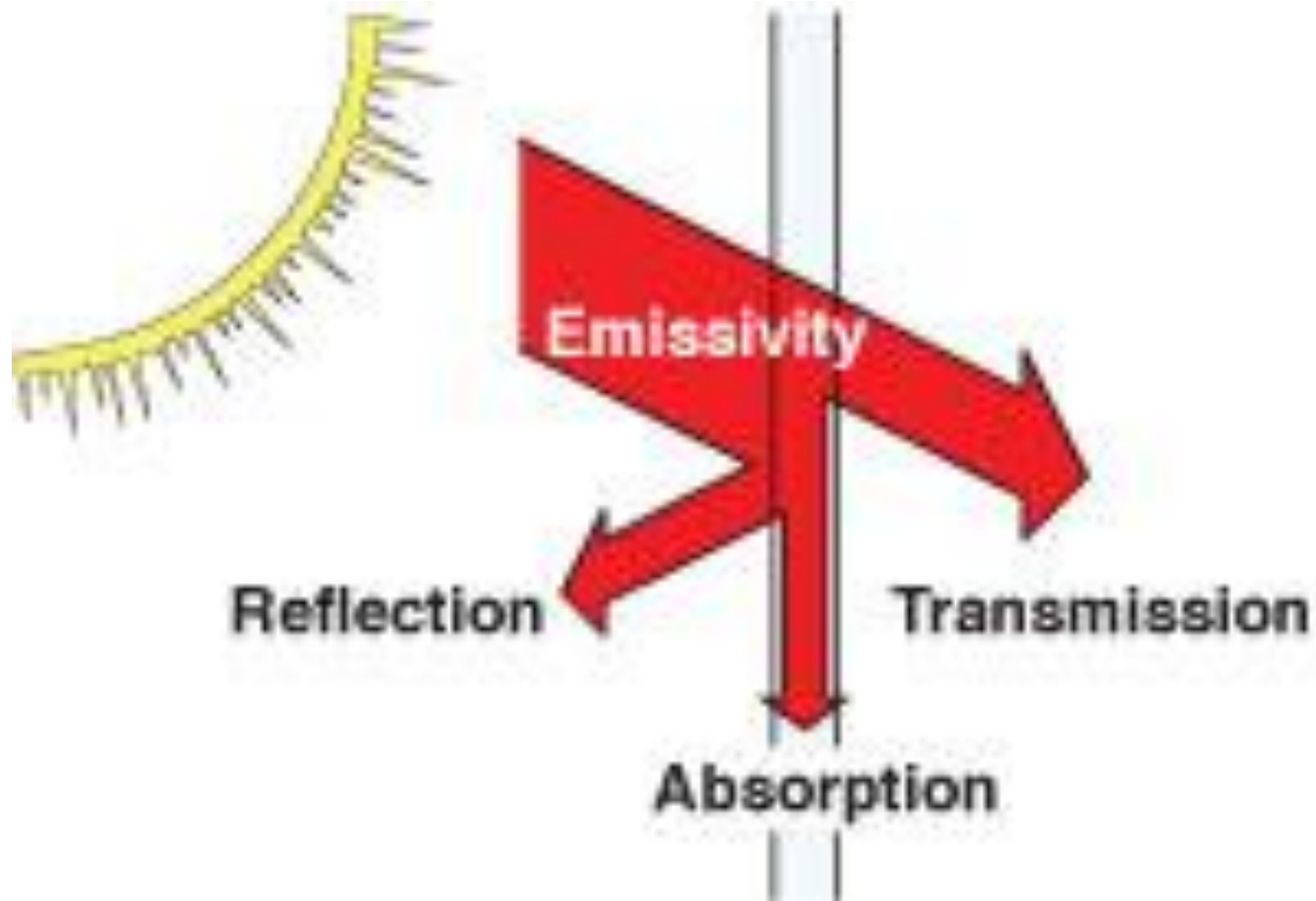
(Aresta et al, 2014. Performance Criteria for Residential Zero Energy Windows, Windows and Daylighting Group, LBNL)

# Conduction, Convection & Radiation

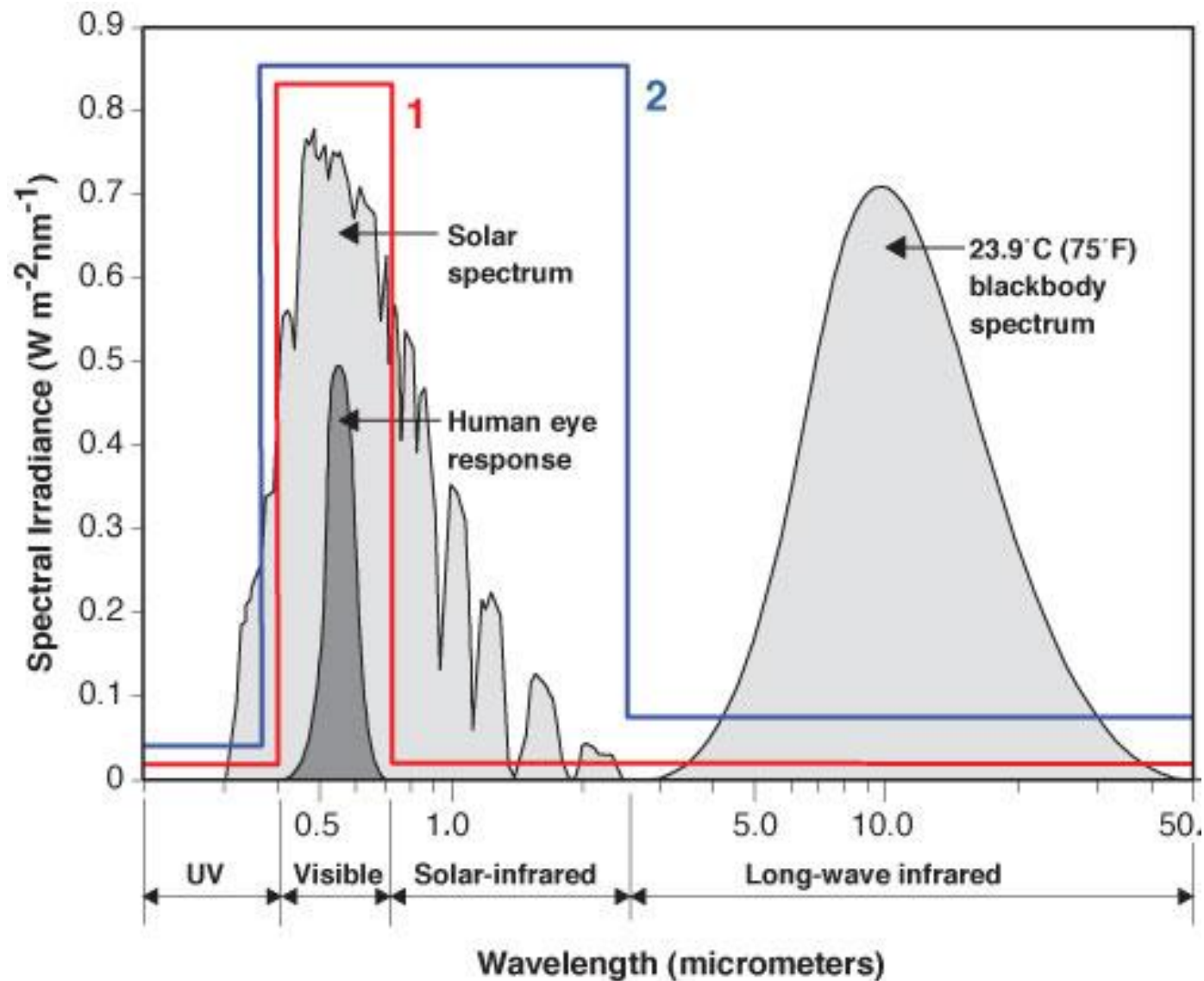
- Heat flows through a window assembly in three ways: conduction, convection, and radiation.
- Conduction is heat traveling through a solid, liquid or gas.
- Convection is the transfer of heat by the movement of gases or liquids, like warm air rising from a candle flame.
- Radiation is the movement of energy through space without relying on conduction through the air or by movement of the air, e.g., the way one feels the “radiant” heat of a fire.

# Radiation Heat Transfer

- There are two distinct types of radiation or radiant heat transfer:
  - 1) Long-wave radiation heat transfer refers to radiant heat transfer between objects at room or outdoor environmental temperatures. These temperatures emit radiation in the range of 3–50 microns.
  - 2) Short-wave radiation heat transfer refers to radiation from the sun (which is at a temperature of 6,000 K) and occurs in the 0.3–2.5 micron range. This range includes the ultraviolet, visible, and solar-infrared radiation.



**The basic properties of glazing  
that affect radiant energy transfer.**



**Ideal spectral transmittance for glazings  
in different climates (Source: McCluney, 1996).**

# Long-wave Radiation (1)

- Idealized transmittance of a glazing with a low-E coating designed for low solar heat gain.
- Visible light is transmitted and solar-infrared radiation is reflected.
- Long-wave infrared radiation is reflected back in to the interior.
- This approach is to reduce solar heat gain and is suitable in almost all climates.

## Short-wave Radiation (2)

- Idealized transmittance of a glazing with a low-E coating designed for high solar heat gain.
- Visible light and solar-infrared radiation are transmitted.
- Long-wave infrared radiation is reflected back in the interior.
- This approach is more commonly used in cold climates where solar gain is wanted.

# **Lack of Wavelength Overlapping Allows for Strategic Glazing**

- Even though the physical process is the same, there is no overlap between long and short wavelength ranges.
- Coatings that control the passage of long-wave or solar radiation in these ranges, through transmission and/or reflection, can contribute significantly to energy savings and have been the subject of significant innovations in recent years.

# Visible Spectrum

- Glazing types vary in their transparency to different parts of the visible spectrum. For example, a glass that appears tinted green as you look through it toward the outdoors transmits more sunlight from the green portion of the visible spectrum and absorbs or reflects more of the other colors.
- Similarly, a bronze-tinted glass absorbs or reflects the blues and greens and transmits the warmer colors. Neutral gray tints absorb or reflect most colors equally.

# Infrared Spectrums

- This same principle applies outside the visible spectrum. Most glass is partially transparent to at least some ultraviolet radiation, while plastics are commonly more opaque to ultraviolet.
- Glass is opaque to long-wave infrared radiation but generally transparent to solar-infrared radiation.
- Strategic utilization of these variations has made for some high-performance glazing products.

# Basic Glazing Properties

- The four basic properties of glazing that affect radiant energy transfer: [transmittance](#), [reflectance](#), [absorptance](#), and [emittance](#).
- There are four properties of windows that are the basis for quantifying energy performance.
- These four concepts—as well as [Light-to-Solar-Gain ratio](#), a ratio of VT/SHGC—have been standardized within the glazing industry, and allow accurate comparison of windows.

# U-factor

- When there is a temperature difference between inside and outside, heat is lost or gained through the window frame and glazing by the combined effects of conduction, convection, and long-wave radiation.
- The U-factor of a window assembly represents its overall heat transfer rate or insulating value.

# Solar Heat Gain Coefficient

- Regardless of outside temperature, heat can be gained through windows by direct or indirect solar radiation.
- The ability to control this heat gain through windows is characterized in terms of the solar heat gain coefficient (SHGC) or shading coefficient (SC) of the window.

# Visible Transmittance

- Visible transmittance (VT or  $T_{vis}$ ), also referred to as visible light transmittance (VLT), is an optical property that indicates the amount of visible light transmitted through the glass.
- It affects energy by providing daylight that creates the opportunity to reduce electric lighting and its associated cooling loads.

# Air Leakage

- Heat loss and gain also occur by air leakage through cracks around sashes and frames of the window assembly.
- This effect is often quantified in terms of the amount of air (cubic feet or cubic meters per minute) passing through a unit area of window (square foot or square meter) under given pressure conditions.

# Transmittance

- Transmittance refers to the percentage of radiation that can pass through glazing.
- Transmittance can be defined for different types of light or energy, e.g., visible transmittance, UV transmittance, or total solar energy transmittance.

# Photopic Sensitivity

- Transmission of visible light determines the effectiveness of a type of glass in providing daylight and a clear view through the window. For example, tinted glass has a lower visible transmittance than clear glass.
- While the human eye is sensitive to light at wavelengths from about 0.4 to 0.7 microns, its peak sensitivity is at 0.55, with lower sensitivity at the red and blue ends of the spectrum. This is referred to as the photopic sensitivity of the eye.

# Total Solar Energy Transmittance

- More than half of the sun's energy is invisible to the eye. Most reaches us as near-infrared with a few percent in the ultraviolet (UV) spectrum.
- Thus, total solar energy transmittance describes how the glazing responds to a much broader part of the spectrum and is more useful in characterizing the quantity of total solar energy transmitted by the glazing.

# Advances in Glazing Technology

- With the recent advances in glazing technology, manufacturers can control how glazing materials behave in these different areas of the spectrum.
- The basic properties of the substrate material (glass or plastic) can be altered, and coatings can be added to the surfaces of the substrates. For example, a window optimized for daylighting and for reducing overall solar heat gains should transmit an adequate amount of light in the visible portion of the spectrum, while excluding unnecessary heat gain from the near-infrared part of the electro-magnetic spectrum.

# Reflectance

- Just as some light reflects off of the surface of water, some light will always be reflected at every glass surface.
- A specular reflection from a smooth glass surface is a mirror-like reflection similar to the image of yourself you see reflected in a store window.
- The natural reflectivity of glass is dependent on the type of glazing material, the quality of the glass surface, the presence of coatings, and the angle of incidence of the light.

# Float Glass

- Today, most glass manufactured in the United States is float glass, which reflects 4% of visible light at each glass-air interface or 8% total for a single pane of clear, uncoated glass.
- The sharper the angle at which the light strikes, however, the more the light is reflected rather than transmitted or absorbed (see figure to the right).
- Even clear glass reflects 50% or more of the sunlight striking it at incident angles greater than about  $80^\circ$ . (The incident angle is formed with respect to a line perpendicular to the glass surface.)

# Low Light Conditions

- The reflectivity of various glass types becomes especially apparent during low light conditions.
- The surface on the brighter side acts like a mirror because the amount of light passing through the window from the darker side is less than the amount of light being reflected from the lighter side.

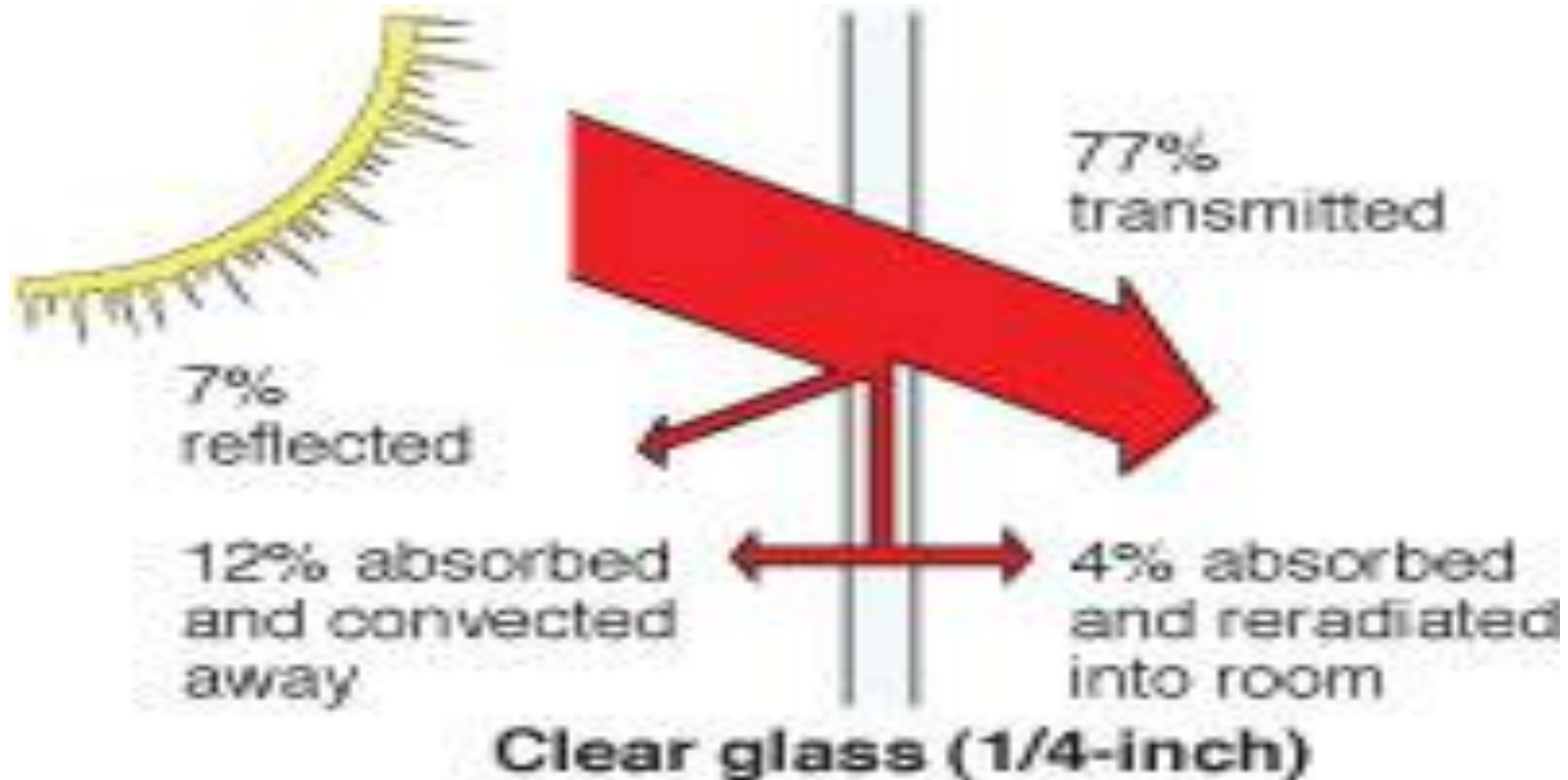
# Glazing Coatings

- This effect can be noticed from the outside during the day and from the inside during the night.
- For special applications when these surface reflections are undesirable (i.e., viewing merchandise through a store window on a bright day), special coatings can virtually eliminate this reflective effect.

# Selective Reflectance

- Most common coatings reflect in all regions of the spectrum.
- However, in the past twenty years, researchers have learned a great deal about the design of coatings that can be applied to glass and plastic to preferentially reflect only selected wavelengths of radiant energy.
- Varying the reflectance of far-infrared and near-infrared energy has formed the basis for high-performance low-E coatings.

**Solar energy transmission through three types of glass under standard ASHRAE conditions.**



# Absorptance

- Energy that is not transmitted through the glass or reflected off its surfaces is absorbed.
- Once glass has absorbed any radiant energy, the energy is transformed into heat, raising the glass temperature.

# Glass Additives

- Typical ¼-inch clear glass absorbs only about 7% of sunlight at a normal angle of incidence (also a 30-degree angle of incidence).
- The absorptance of glass is increased by glass additives that absorb solar energy.
- If they absorb visible light, the glass appears dark.
- If they absorb ultraviolet radiation or near-infrared, there will be little or no change in visual appearance.

# Dark-tinted Glass

- Clear glass absorbs very little visible light, while dark-tinted glass absorbs a considerable amount.
- The absorbed energy is converted into heat, warming the glass.
- Thus, when "heat-absorbing" glass is exposed to the sun, it feels much hotter to the touch than clear glass.

# Tint Colors

- Tints are generally gray, bronze, or blue-green and were traditionally used to lower the solar heat gain coefficient and to control glare.
- Since they block some of the sun's energy, they reduce the cooling load placed on the building and its air-conditioning equipment.
- The effectiveness of heat-absorbing single glazing is significantly reduced if cool, conditioned air flows across the glass.
- Absorption is not the most efficient way to reduce cooling loads, as discussed later.

# Long-wave Infrared Energy

- All glass and most plastics, however, are generally very absorptive of long-wave infrared energy.
- This property is best illustrated in the use of clear glass for greenhouses, where it allows the transmission of intense solar energy but blocks the retransmission of the low-temperature heat energy generated inside the greenhouse and radiated back to the glass.

# Emittance

- When solar energy is absorbed by glass, it is either convected away by moving air or reradiated by the glass surface.
- This ability of a material to radiate energy is called its emissivity.
- Window glass, along with all other objects, typically emit, or radiate, heat in the form of long-wave far-infrared energy.

# Radiant Heat

- The wavelength of the long-wave far-infrared energy varies with the temperature of the surface.
- This emission of radiant heat is one of the important heat transfer pathways for a window. Thus, reducing the window's emission of heat can greatly improve its insulating properties.

# Low-E Glazing

- Standard clear glass has an emittance of 0.84 over the long-wave infrared portion of the spectrum, meaning that it emits 84% of the energy possible for an object at room temperature.
- It also means that for long-wave radiation striking the surface of the glass, 84% is absorbed and only 16% is reflected.
- By comparison, low-E glass coatings have an emittance as low as 0.04. This glazing would emit only 4% of the energy possible at its temperature, and thus reflect 96% of the incident long-wave infrared radiation.

# Basic Glass Properties

- Visible Transmittance (VT or  $T_{vis}$ )
- Solar Heat Gain Coefficient (SHGC)
- U-value and inverse R-value

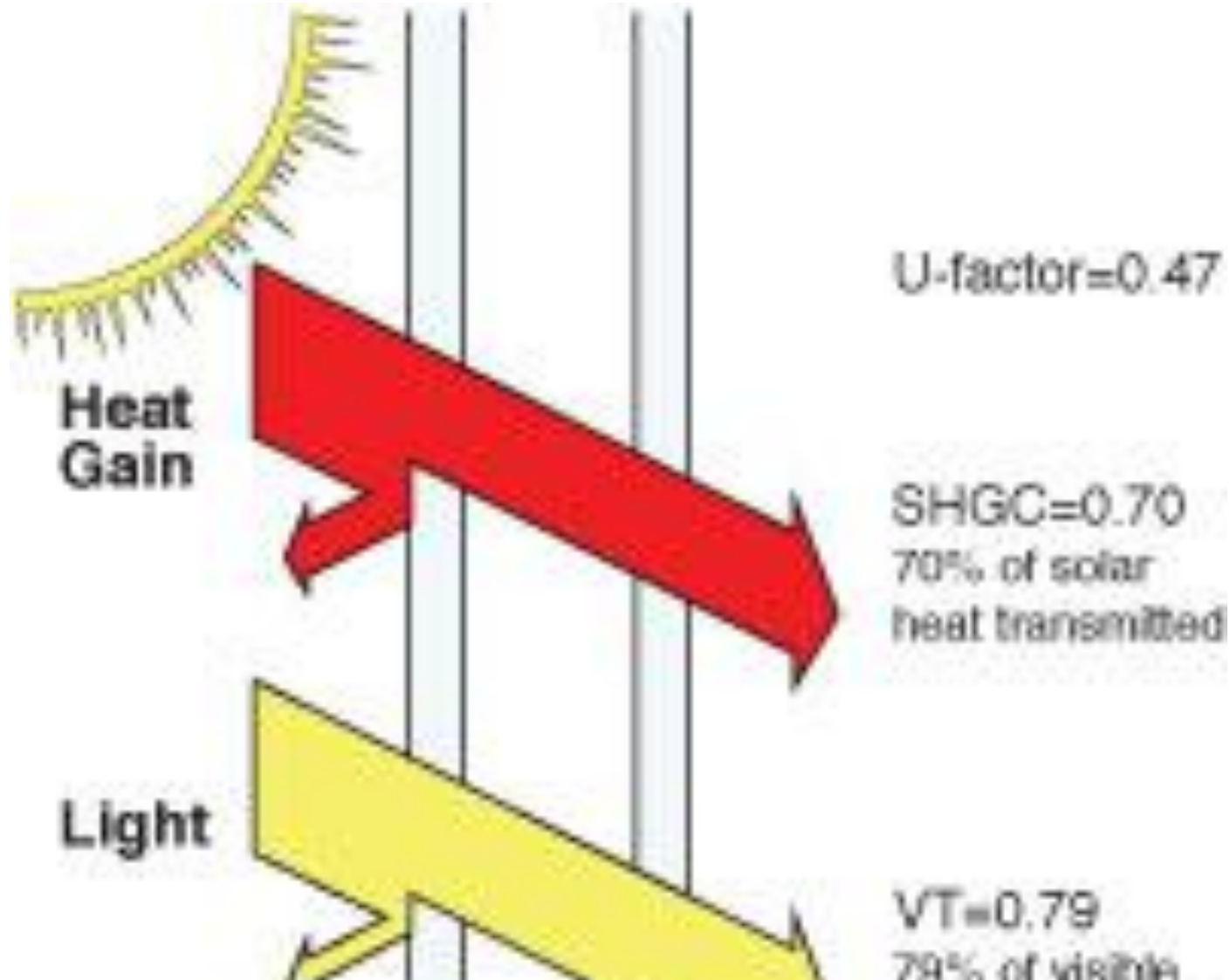
# VT or T<sub>vis</sub>

- Visible transmittance is the amount of light in the visible portion of the spectrum that passes through a glazing material.
- A higher VT means there is more daylight in a space which, if designed properly, can offset electric lighting and its associated cooling loads.
- Visible transmittance is influenced by the glazing type, the number of panes, and any glass coatings.

# Reflective Coatings

- Visible transmittance of glazing ranges from above 90% for uncoated water-white clear glass to less than 10% for highly [reflective coatings](#) on tinted glass.
- A typical double-pane IGU has a VT of around 78%. This value decreases somewhat by adding a [low-E coating](#) and decreased substantially when adding a [tint](#).
- VT values for the whole window are always less than center-of-glass values since the VT of the frame is zero.

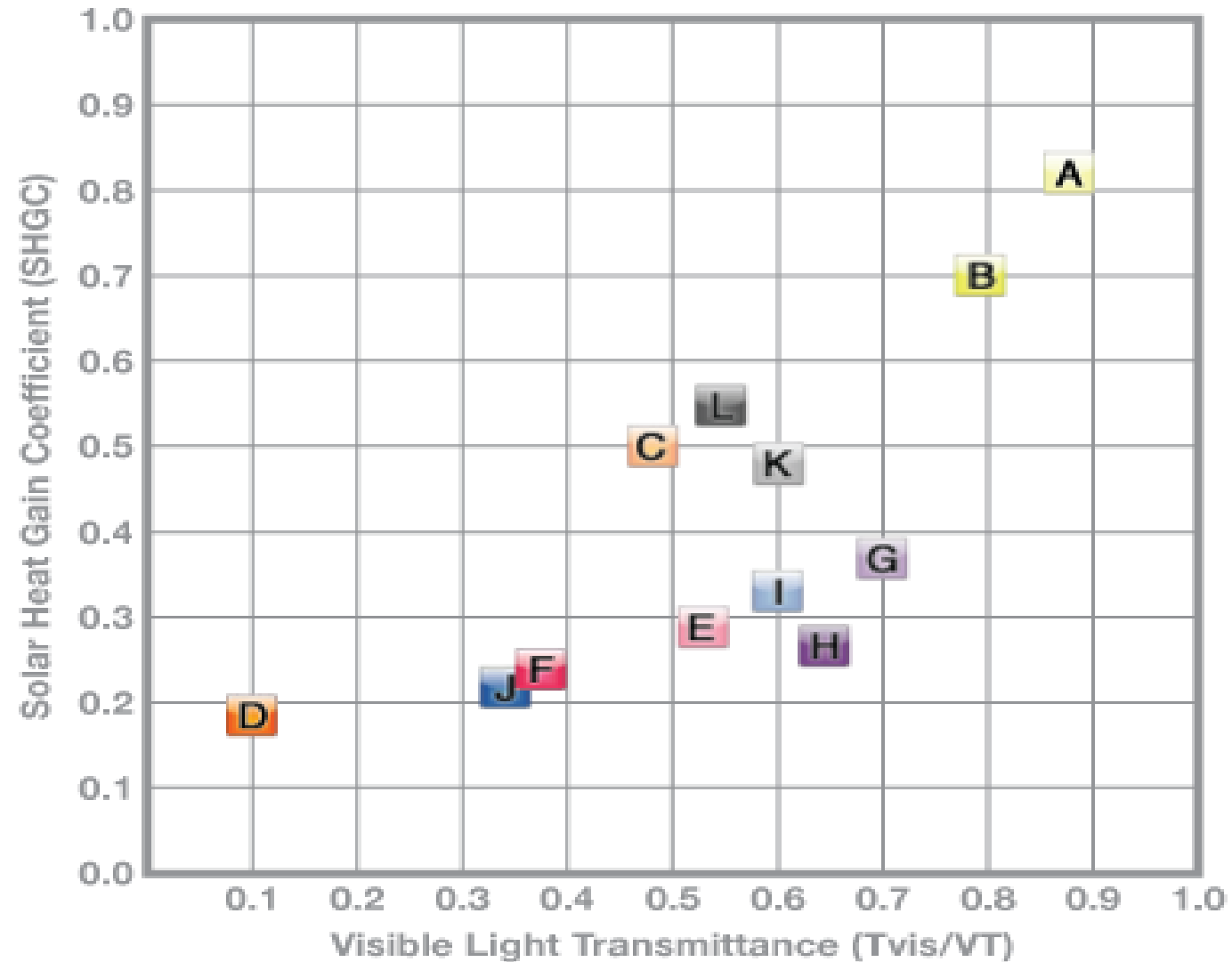
## Center-of-glass visible transmittance values of double pane units.



# Light-to-Solar-Gain Ratio

- In the past, windows that reduced solar gain (with tints and coatings) also reduced visible transmittance. However, new high-performance tinted glass and low-solar-gain low-E coatings have made it possible to reduce solar heat gain with little reduction in visible transmittance.
- Because the concept of separating solar gain control and light control is so important, measures have been developed to reflect this. The LSG ratio is defined as a ratio between visible transmittance (VT) and solar heat gain coefficient (SHGC).

**This image for a double glazed unit illustrates the center-of-glass properties for the options used in the Facade Design Tool.**



# Refer to above Graph

- A double-glazed unit with clear glass (B) has a visible transmittance (VT) of 0.79 and a solar heat gain coefficient (SHGC) of 0.70, so the LSG is  $VT/SHGC = 1.12$ .
- Bronze-tinted glass in a double-glazed unit (C) has a visible transmittance of 0.45 and a solar heat gain coefficient of 0.50, which results in an LSG ratio of 0.89.
- This illustrates that while the bronze tint lowers the SHGC, it lowers the VT even more compared to clear glass.

## **Refer to above Graph cont.**

- The double-glazed unit with a high-performance tint (E) has a relatively high VT of 0.52 but a lower SHGC of 0.29, resulting in an LSG of 1.80—significantly better than the bronze tint.
- A clear double-glazed unit with a low-solar-gain low-E coating (H) reduces the SHGC significantly, to 0.27, but retains a relatively high VT of 0.64, producing an LSG ratio of 2.4—far superior to those for clear or tinted glass.

# Solar Heat Gain Coefficient (SHGC)

- The second major energy-performance characteristic of windows is the ability to control solar heat gain through the glazing.
- Solar heat gain through windows is a significant factor in determining the cooling load of many commercial buildings.
- The origin of solar heat gain is the direct and diffuse radiation coming from the sun and the sky (or reflected from the ground and other surfaces).

# Solar Radiation

- Some radiation is directly transmitted through the glazing to the building interior, and some may be absorbed in the glazing and indirectly admitted to the inside.
- Some radiation absorbed by the frame will also contribute to overall window solar heat gain factor.
- Other thermal (nonsolar) heat transfer effects are included in the U-factor of the window.

# Shading Coefficient

- Window standards are now moving away from a previous standard referred to as Shading Coefficient (SC) to Solar Heat Gain Coefficient (SHGC), which is defined as that fraction of incident solar radiation that actually enters a building through the entire window assembly as heat gain.
- To perform an approximate conversion from SC to SHGC, multiply the SC value by 0.87.

# Interpreting SHGC

- The SHGC is also affected by shading from the frame as well as the ratio of glazing and frame.
- The SHGC is expressed as a dimensionless number from 0 to 1.
- A high coefficient signifies high heat gain, while a low coefficient means low heat gain.

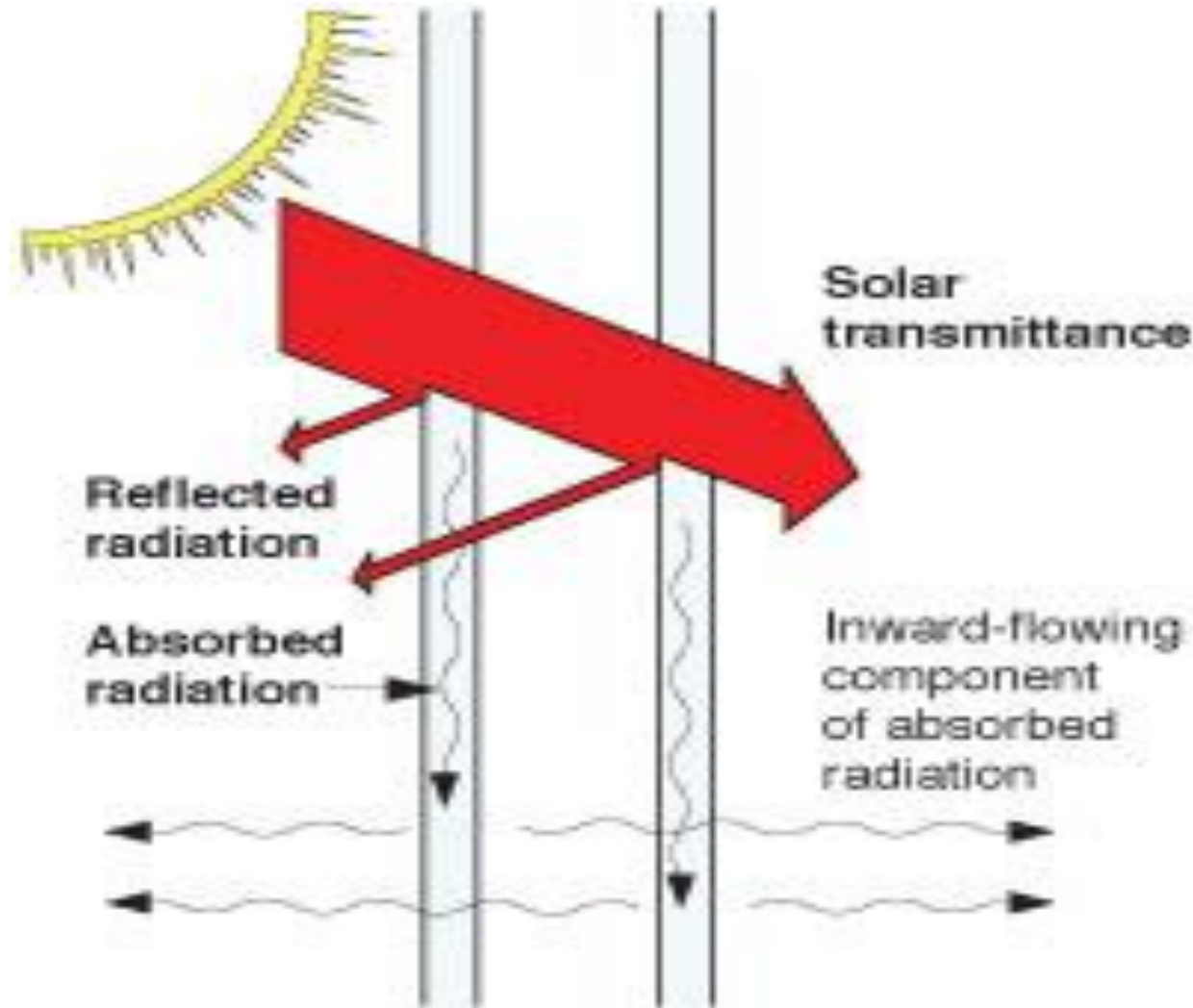
# SHGC Factors

- Solar heat gain is influenced by the glazing type, the number of panes, and any glass coatings.
- Solar heat gain of glazing ranges from above 80% for uncoated water-white clear glass to less than 20% for highly [reflective coatings](#) on tinted glass.

# Whole Window vs. COG Values

- A typical double-pane IGU has a SHGC of around 0.70.
- This value decreases somewhat by adding a [low-E coating](#) and decreased substantially when adding a [tint](#) (see figure to the right).
- Since the area of a frame has a very low SHGC, the overall window SHGC is lower than the center-of-glass value.

**Simplified view of the components of solar heat gain.**  
**Heat gain includes the transmitted solar energy and**  
**the inward flowing component of absorbed radiation.**



# U-factor (Insulating Value)

- For windows, a principle energy concern is their ability to control heat loss.
- Heat flows from warmer to cooler bodies, thus from the inside face of a window to the outside in winter, reversing direction in summer.

# Thermal Resistance

- Overall heat flow from the warmer to cooler side of a window unit is a complex interaction of all three basic heat transfer mechanisms—conduction, convection, and long-wave radiation.
- A window assembly's capacity to resist this heat transfer is referred to as its insulating value, or u-factor.

# Thermal Breaks

- Conduction occurs directly through glass, and the air cavity within double-glazed IGUs, as well as through a window's spacers and frames.
- Some frame materials, like wood, have relatively low conduction rates.
- The higher conduction rates of other materials, like metals, have to be mitigated with discontinuities, or thermal breaks, in the frame to avoid energy loss.

# Internal Thermal Convection

- Convection within a window unit occurs in three places: the interior and exterior glazing surfaces, and within the air cavity between glazing layers.
- On the interior, a cold interior glazing surface chills the adjacent air. This denser cold air then falls, starting a convection current.
- People often perceive this air flow as a draft caused by leaky windows, instead of recognizing that the remedy correctly lies with a window that provides a warmer glass surface (see figure to the right).

# External Thermal Convection

- On the exterior, the air film against the glazing contributes to the window's insulating value. As wind blows (convection), the effectiveness of this air film is diminished, contributing to a higher heat rate loss.
- Within the air cavity, temperature-induced convection currents facilitate heat transfer.
- By adjusting the cavity width, adding more cavities, or choosing a gas fill that insulates better than air, windows can be designed to reduce this effect.

# Radiant Heat Exchange

- All objects emit invisible thermal radiation, with warmer objects emitting more than colder ones.
- Through radiant exchange, the objects in the room, and especially the people (who are often the warmest objects), radiate their heat to the colder window.

# Body Heat Loss & Gain

- People often feel the chill from this radiant heat loss, especially on the exposed skin of their hands and faces, but they attribute the chill to cool room air rather than to a cold window surface.
- Similarly, if the glass temperature is higher than skin temperature, which occurs when the sun shines on heat-absorbing glass, heat will be radiated from the glass to the body, potentially producing thermal discomfort.

# Determining Insulating Value

- The U-factor (also referred to as U-value) is the standard way to quantify overall heat flow.
- For windows, it expresses the total heat transfer coefficient of the system (in Btu/hr-sf-°F), and includes conductive, convective, and radiative heat transfer.

# **Btu/hr f<sup>2</sup>·°F**

- The U-value represents heat flow per hour (in Btus per hour or watts) through each square foot of window for a 1 degree Fahrenheit temperature difference between the indoor and outdoor air temperature.
- The insulating value or R-value (resistance to heat transfer) is the reciprocal of the total U-factor ( $R=1/U$ ).
- The higher the R-value of a material, the higher the insulating value; the smaller the U-factor, the lower the rate of heat flow.

# Total Window vs. COG

- Given that the thermal properties and the various materials within a window unit, the U-factor is commonly expressed in two ways:
  - The U-factor of the total window assembly combines the insulating value of the glazing proper, the edge effects in the IGU, and the window frame and sash.
  - The center-of-glass U-factor assumes that heat flows perpendicular to the window plane, without addressing the impact of the frame edge effects and material.

# Total Window vs. COG cont.

- The U-factor of the glazing portion of the window unit is affected primarily by the total number of glazing layers (panes), their dimension, the type of gas within their cavity, and the characteristic of coatings on the various glazing surfaces.
- As windows are complex three-dimensional assemblies, in which materials and cross sections change in a relatively short distance, it is limiting, however, to simply consider glazing. For example, metal spacers at the edge of an IGU have a much higher heat flow than the center of the insulating glass, which causes increased heat loss along the outer edge of the glass.

# Overall U-factor

- The relative impact of these "edge effects" becomes more important as the insulating value of the entire assembly increases, and in small units where the ratio of edge to center-of-glass area is high.
- Since the U-factors vary for the glass, edge-of-glass zone, and frame, it can be misleading to compare the U-factors of windows from different manufacturers if they are not carefully and consistently described.
- Calculation methods developed by the [National Fenestration Rating Council](#) (NFRC) address this concern.

# Winter U-factor

- In addition to the thermal properties of window assembly materials, weather conditions, such as interior/exterior temperature differential and wind speed, also impact U-factor.
- Window manufacturers typically list a winter U-factor for determined under relatively harsh conditions: 15 mph wind, 70 degrees Fahrenheit indoors, 0 degrees Fahrenheit outdoors.

# U-value Protocols

- A specific set of assumptions and procedures must be followed to calculate the overall U-factor of a window unit using the NFRC method. For instance, the NFRC values are for a standard window size-the actual U-factor of a specific unit varies with size.
- Originally developed for manufactured window units, new methods are available to determine the U-factor of site-built assemblies.

# Vertical Position

- The U-factor of a window unit is rated based on a vertical position.
- A change in mounting angle affects a window's U-factor.
- The same unit installed on a sloped roof at  $20^\circ$  from horizontal would have a U-factor 10–20% higher than in the vertical position (under winter conditions).

# Glazing Treatments

- Various treatments are utilized in the glazing industry:
  - Low-E Coatings
  - Tints
  - Laminates
  - Surface Treatments
  - Applied Films

# Low-E Coatings

- When heat or light energy is absorbed by glass, it is either convected away by moving air or reradiated by the glass surface.
- The ability of a material to radiate energy is called its emissivity.
- All materials, including windows, emit (or radiate) heat in the form of long-wave, far-infrared energy depending on their temperature.
- This emission of radiant heat is one of the important components of heat transfer for a window.
- Thus reducing the window's emittance can greatly improve its insulating properties.

# Clear Glass Emittance

- Standard clear glass has an emittance of 0.84 over the long-wave portion of the spectrum, meaning that it emits 84% of the energy possible for an object at its temperature.
- It also means that 84% of the long-wave radiation striking the surface of the glass is absorbed and only 16% is reflected.

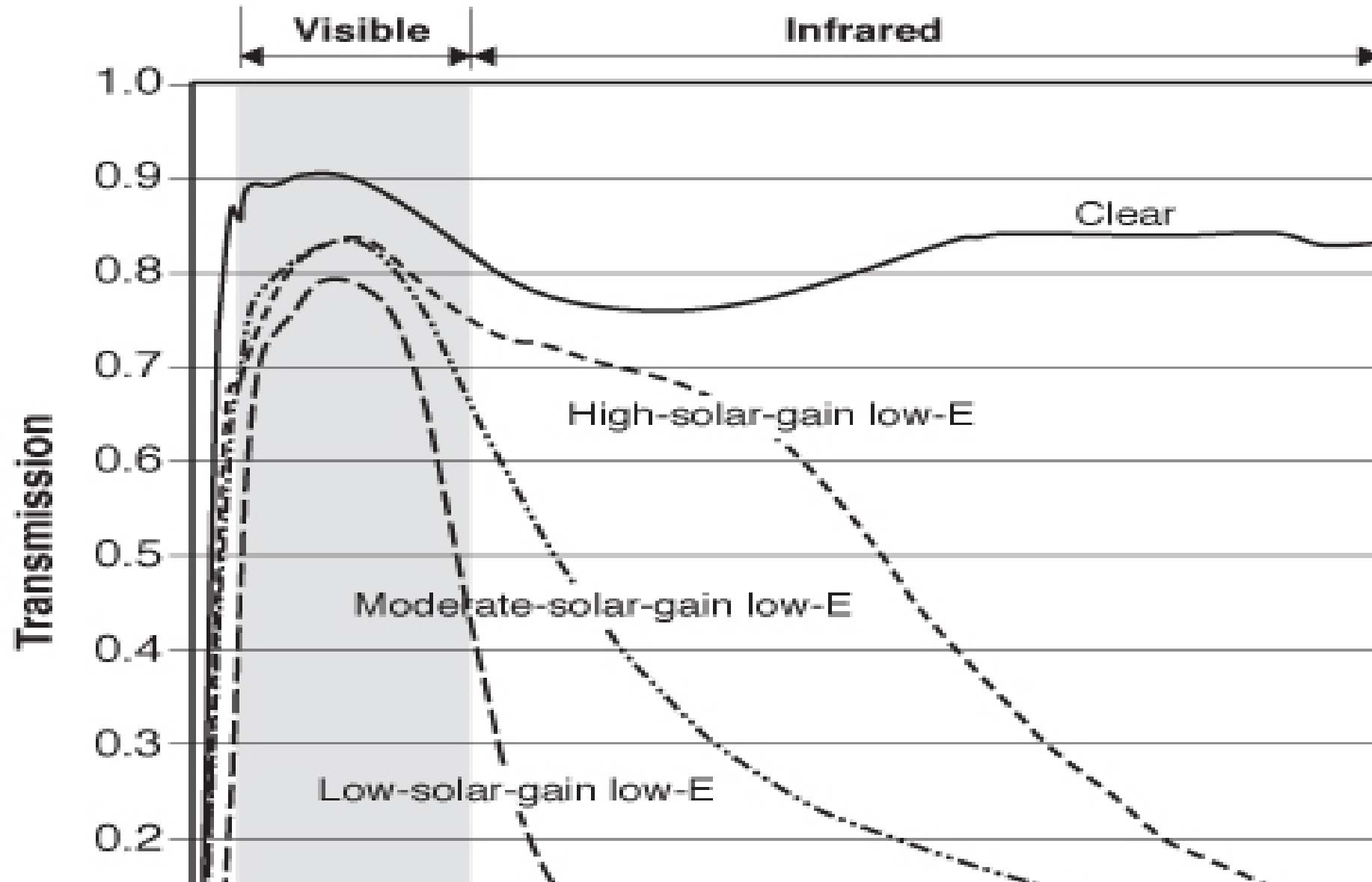
# Low-E Coatings

- By comparison, low-E glass coatings can have an emittance as low as 0.04. Such glazing would emit only 4% of the energy possible at its temperature, and thus reflect 96% of the incident long-wave, infrared radiation.
- Window manufacturers' product information may not list emittance ratings. Rather, the effect of the low-E coating is incorporated into the U-factor for the unit or glazing assembly.

# Spectrally Selective Coatings

- The solar reflectance of low-E coatings can be manipulated to include specific parts of the visible and infrared spectrum.
- This is the origin of the term spectrally selective coatings, which selects specific portions of the energy spectrum, so that desirable wavelengths of energy are transmitted and others specifically reflected.
- A glazing material can then be designed to optimize energy flows for solar heating, daylighting, and cooling.

## Spectral transmittance curves for glazings with low-emittance coatings (Source: Lawrence Berkeley National Laboratory).



# Low U-val; High SHGC & Tvis

- With conventional clear glazing, a significant amount of solar radiation passes through the window, and heat from objects within the space is reradiated back into the glass, then from the glass to the outside of the window.
- A glazing design for maximizing energy efficiency during underheated periods would ideally allow all of the solar spectrum to pass through, but would block the reradiation of heat from the inside of the space.
- The first low-E coatings, intended mainly for residential applications, were designed to have a high solar heat gain coefficient and a high visible transmittance to allow the maximum amount of sunlight into the interior while reducing the U-factor significantly.

# Low U-val & SHGC; High Tvis

- A glazing designed to minimize summer heat gains, but allow for some daylighting, would allow most visible light through, but would block all other portions of the solar spectrum, including ultraviolet and near-infrared radiation, as well as long-wave heat radiated from outside objects, such as pavement and adjacent buildings.
- These second-generation low-E coatings still maintain a low U-factor, but are designed to reflect the solar near-infrared radiation, thus reducing the total SHGC while providing high levels of daylight transmission (see figure to the right).

# Low-E Flexibility

- Low-solar-gain coatings reduce the beneficial solar gain that could be used to offset heating loads.
- In commercial buildings, it is common to apply low-E coatings to both tinted and clear glass. While the tint lowers the visible transmittance somewhat, it contributes to solar heat gain reduction and glare control.
- Low-E coatings can be formulated to have a broad range of solar control characteristics while maintaining a low U-factor.

# Sputtered Coatings

- There are two basic processes for making low-E coatings—sputtered and pyrolytic.
- Sputtered coatings are multilayered coatings that are typically comprised of metals, metal oxides, and metal nitrides. These materials are deposited on glass or plastic film in a vacuum chamber in a process called physical vapor deposition.
- Although these coatings range from three to possibly more than thirteen layers, the total thickness of a sputtered coating is only one ten thousandth the thickness of a human hair.

# Soft-coat Low-E

- Sputtered coatings often use one or more layers of silver to achieve their heat reflecting properties. Since silver is an inherently soft material that is susceptible to corrosion, the silver layer(s) must be surrounded by other materials that act as barrier layers to minimize the effects of humidity and physical contact.
- Historically, sputtered coatings were described as soft-coat low-E because they offered little resistance to chemical or mechanical attack.
- While advances in material science have significantly improved the chemical and mechanical durability of some sputtered coatings, the glass industry continues to generically refer to sputter coat products as "soft-coat low-E."

## **$T_{vis}$ 0.02**

- Most sputtered coatings are not sufficiently durable to be used in monolithic applications; however, when the coated surface is positioned facing the air space of a sealed insulating glass unit, the coating should last as long as the sealed glass unit.
- Sputtered coatings have emittance as low as 0.02 which are substantially lower than those for pyrolytic coatings.

# Hard Pyrolytic Coatings

- A typical pyrolytic coating is a metallic oxide, most commonly tin oxide with some additives, which is bonded to the glass while it is in a semi-molten state.
- The process by which the coating is applied to the glass is called chemical vapor deposition. The result is a baked-on surface layer that is quite hard and thus very durable, which is why pyrolytic low-E is sometimes referred to as "hard-coat low-E."

# Pyrolytic Coatings cont.

- A pyrolytic coating can be ten to twenty times thicker than a sputtered coating but is still extremely thin.
- Pyrolytic coatings can be exposed to air and cleaned with traditional glass cleaning products and techniques without damaging the coating.

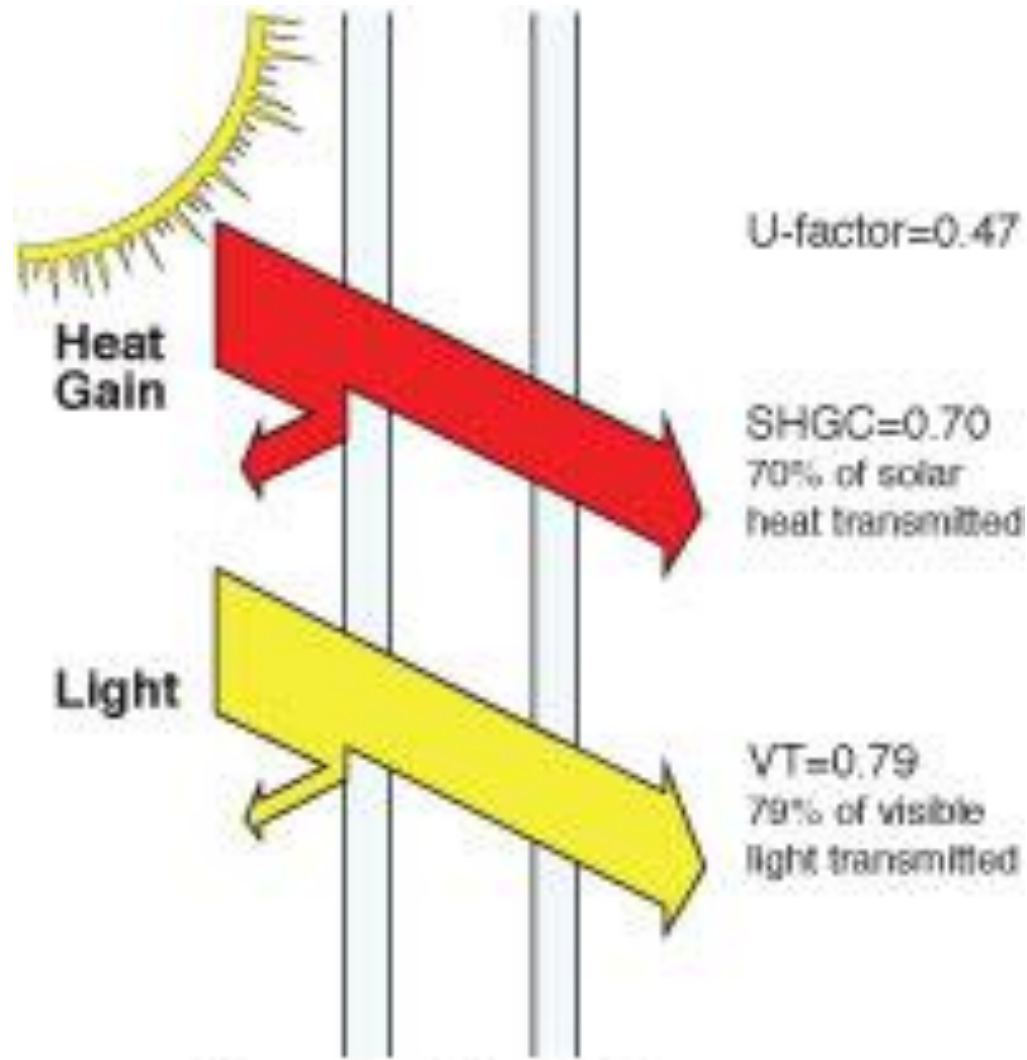
# Chemical & Mechanical Durability

- Because of their inherent chemical and mechanical durability, pyrolytic coatings may be used in monolithic applications, subject to manufacturer approval.
- They are also used in multi-layer window systems where there is air flow between the glazings as well as with non-sealed glazed units.
- In general pyrolytic low-E is most commonly used in sealed insulating glass units with the low-E surface facing the sealed air space.

# Low-E & SF Technologies

- Low-solar-gain low-E coatings on plastic films can also be applied to existing glass as a retrofit measure, thus reducing the SHGC of an existing clear glass considerably while maintaining a high visible transmittance and lower U-factor.
- Other conventional tinted and reflective films will also reduce the SHGC but at the cost of lower visible transmittance.
- Reflective mirror-like metallic films can also decrease the U-factor, since the surface facing the room has a lower emittance than uncoated glass.

## Center-of-glass values of double pane units with and without low-E coatings.



# Reflective Coatings

- As the SHGC falls in single-pane tinted glazings, the daylight transmission (VT) drops even faster, and there are practical limits on how low the SHGC can be made using tints.
- If larger reductions are desired, a reflective coating can be used to lower the solar heat gain coefficient by increasing the surface reflectivity of the material.
- These coatings usually consist of thin metallic or metal oxide layers.
- The reflective coatings come in various metallic colors—silver, gold, bronze—and they can be applied to clear or tinted glazing.

# Reducing SHGC

- The solar heat gain coefficient can be reduced by varying degrees, depending on the thickness and reflectivity of the coating, and its location in the glazing system.
- Some reflective coatings are durable and can be applied to exposed surfaces; others must be protected in sealed insulating glass units.
- The emittance of the coating creates modest changes in the U-factor.

# Suspended Film Coatings

- Similar to tinted films in retrofit situations, reflective coatings may be applied to the inner glass surface of an existing window by means of an adhesive-bonded, metallic-coated plastic film.
- The applied films are effective at reducing solar gains but are not as durable as some types of coated glass.

# Visible Transmittance

- As with tinted glazing, the visible transmittance of a reflective glazing usually declines more than the solar heat gain coefficient.
- Reflective glazings are usually used in commercial buildings for large windows, for hot climates, or for windows with substantial solar heat gains.
- Reflective glazing is also used by many architects because of its glare control and uniform, exterior appearance.

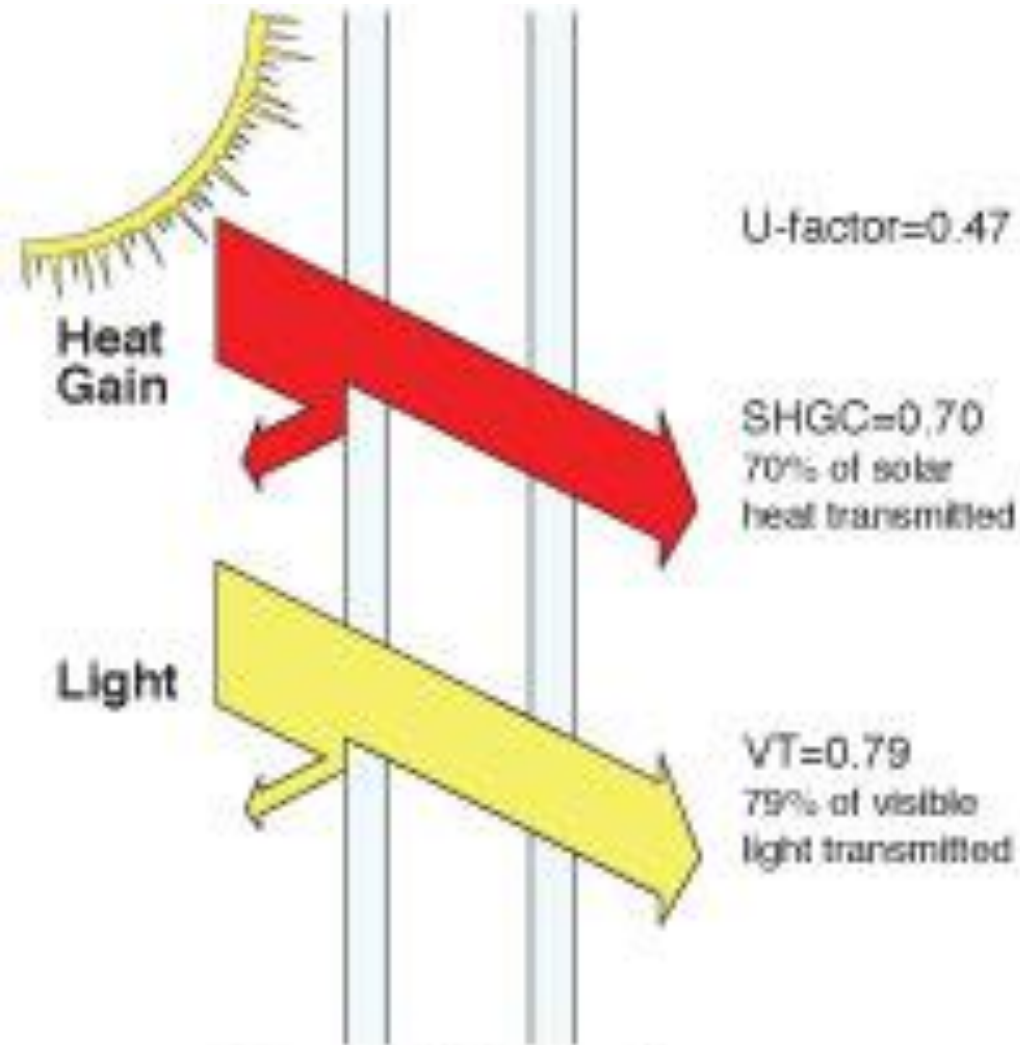
# Reflective Glazing Effects

- Special consideration should always be given to the effect of the reflective glazing on the outside.
- Acting like a mirror, the reflective glass intensifies the sun's effects, and should be avoided (or is not permitted by local zoning regulations) in some locations because of its impact on adjacent buildings.

# Visual Privacy

- It is also important to remember that reflective glass acts like a mirror on the side facing the light.
- Thus, a reflective window that acts like a mirror to the outside during the day will look like a mirror on the inside during the night.
- These coatings will not provide visual privacy at night if interior lights are on.

## Center-of-glass values of double pane units with and without reflective coating.



# Tints

- Glass is available in a number of tints which absorb a portion of the solar heat and block daylight.
- Tinting changes the color of the window and can increase visual privacy.
- The primary uses for tinted glass are reducing glare from the bright outdoors and reducing the amount of solar energy transmitted through the glass.

# Tinted Colors

- Tinted glazings retain their transparency from the inside, although the brightness of the outward view is reduced and the color is changed.
- The most common colors are neutral gray, bronze, and blue-green, which do not greatly alter the perceived color of the view and tend to blend well with other architectural colors.

# Inorganic Additives

- Tinted glass is made by altering the chemical formulation of the glass with special inorganic additives.
- The color is durable and does not change over time. Its color and density changes with the thickness of the glass. Coatings can also be applied after manufacture.
- Every change in color or combination of different glass types affects [visible transmittance](#), [solar heat gain coefficient](#), [reflectivity](#), and other properties.
- Glass manufacturers list these properties for every color, thickness, and assembly of glass type they produce.

# Maximizing Absorption

- Tinted glazings are specially formulated to maximize their absorption across some or all of the solar spectrum and are often referred to as heat-absorbing.
- All of the absorbed solar energy is initially transformed into heat within the glass, thus raising the glass temperature.
- Depending upon climatic conditions, up to 50% of the heat absorbed in a single pane of tinted glass may then be transferred to the inside via radiation and convection.
- Thus, there may be only a modest reduction in overall solar heat gain compared to other glazings.

# Heat Gain

- This heat gain from absorption that is transmitted to the room leads to discomfort near tinted windows as well.
- Heat-absorbing glass provides more effective sun control when used as the outer layer of a double-pane window.
- Traditional tinted glazing, bronze and gray, often force a trade-off between visible light and solar gain.
- There is a greater reduction in visible transmittance than in solar heat gain coefficient.

# Daylighting

- Tinted glass can decrease glare by reducing the apparent brightness of the glass surface, but it also diminishes the amount of daylight entering the room.
- For windows where daylighting is desirable, it may be more satisfactory to use a high-performance tint or coating along with other means of controlling glare.
- Tinted glazings can provide a measure of visual privacy during the day, when they reduce visibility from the outdoors.
- However, at night the effect is reversed and it is more difficult to see outdoors from the inside, especially if the tint is combined with a reflective coating.

# Spectrally Selective

- To address the problem of reducing daylight with traditional tinted glazing, glass manufacturers have developed high-performance tinted glass that is sometimes referred to as spectrally selective.
- This glass preferentially transmits the daylight portion of the solar spectrum but absorbs the near-infrared part of sunlight. This is accomplished with special additives during the float glass process.
- Like other tinted glass, it is durable and can be used in both monolithic and multiple-glazed window applications.

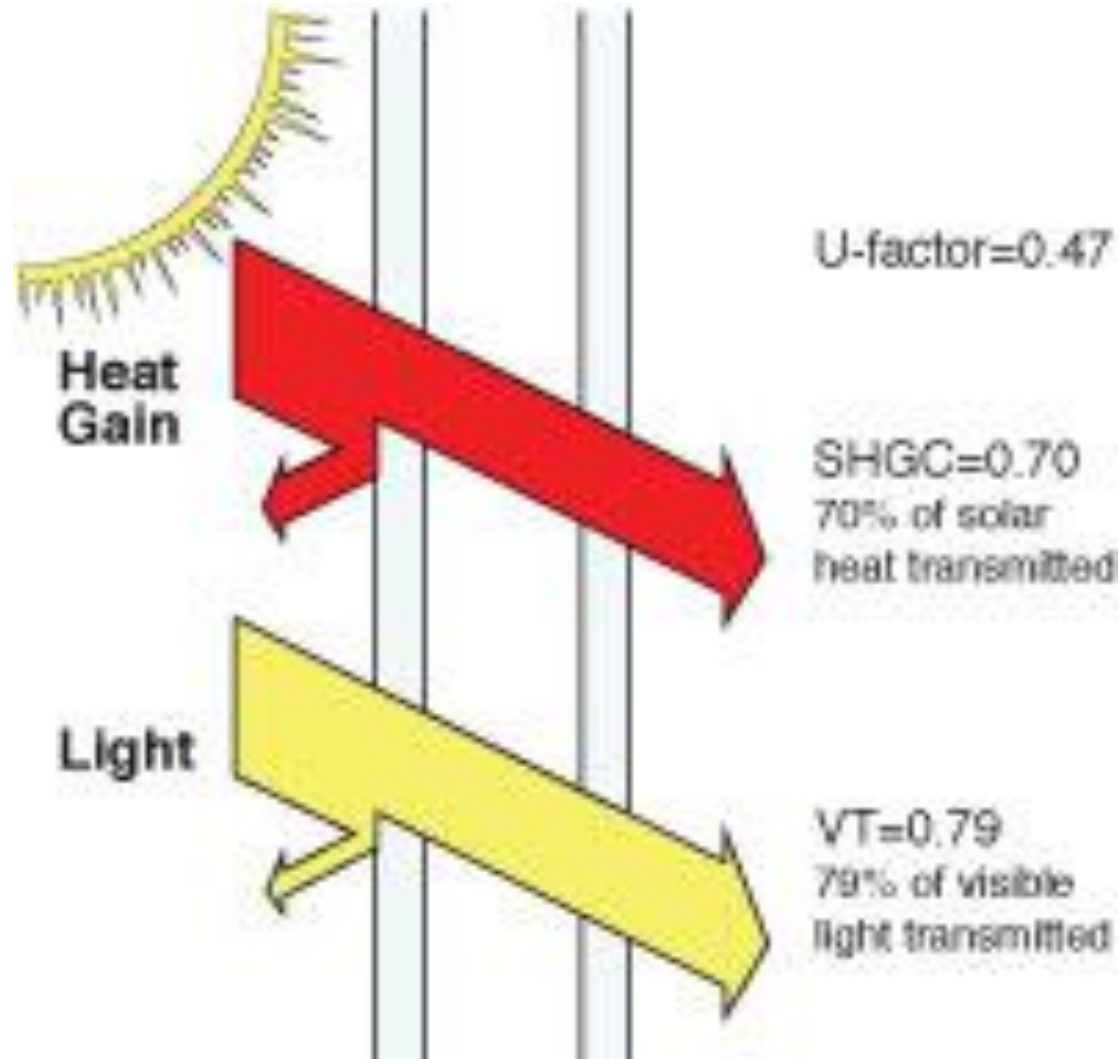
# Spectrally Selective cont.

- Spectrally selective glazings have a light blue or light green tint and have higher visible transmittance values than traditional bronze- or gray-tinted glass, but have lower solar heat gain coefficients.
- Because they are absorptive, they are best used as the outside glazing in a double-glazed unit. They can also be combined with low-E coatings to enhance their performance further.
- High-performance tinted glazings provide a substantial improvement over conventional clear, bronze, and gray glass, and a modest improvement over the existing green and blue-green color-tinted glasses that already have some selectivity.

# Retrofits

- Tinted glazing is more common in commercial windows than in residential windows.
- In retrofit situations, when windows are not being replaced, tinted plastic film may be applied to the inside surface of the glazing.
- The applied tinted films provide some reduction in solar gain compared to clear glass but are not as effective as spectrally selective films or reflective glue-on films, and are not as durable as tinted glass.

## Center-of-glass values of double pane units with and without tints.



# Laminates

- Laminated glass consists of a tough plastic interlayer made of polyvinyl butyral (PVB) bonded between two panes of glass under heat and pressure.
- Once sealed, the glass sandwich behaves as a single unit and looks like normal glass.
- Laminated glass provides durability, high performance, and multifunctional benefits while preserving aesthetic appearance.

# Prevent Shattering

- Similar to car windshield glass, laminated glass may crack upon impact, but the glass fragments tend to adhere to the plastic interlayer rather than falling free and potentially causing injury.
- Laminated glass resolves many design problems, offering increased protection from the effects of disasters such as hurricanes, earthquakes, and bomb blasts.

# IGU Packages

- Annealed, heat-strengthened, or tempered glass can be used to produce laminated glass; the glass layers may be of equal or unequal thickness.
- With respect to solar control, laminated glass retains the characteristics of the glass making up the assembly.
- Reflective coatings and frit patterns may also be applied within a laminated glass sandwich.
- Laminated glass can also be used as a component of an insulated glazing unit.

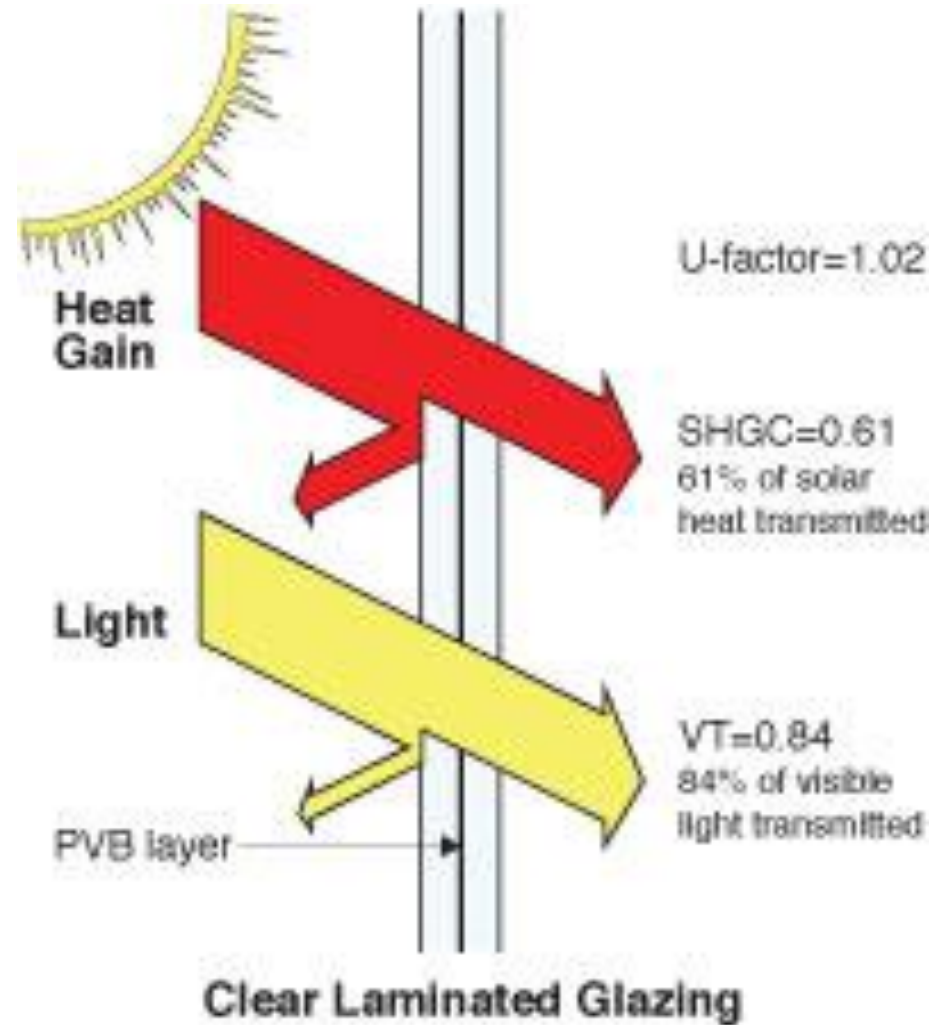
# Energy Performance

- Single-pane laminated glass with a spectrally selective low-E sputtered coating on plastic film sandwiched between two panes of glass offers the energy performance of single-pane, spectrally selective glass and the safety protection of laminated glass.
- However, in this configuration, since the low-E surface is not exposed to an air space, the lower emittance has no effect on the glazing U-factor and SHGC.
- With double-pane laminated glass, the full benefit of the low-E coating can be realized by placing the coating on one of the glass surfaces facing the air space.

# Acoustic Properties

- Glass has inherently poor acoustic properties, but laminated glass, alone or combined with additional glass plies to form a sealed, insulating glass unit, outperforms other glazing assemblies.
- Laminated glass reduces noise transmission due to the PVB layer's sound-dampening characteristics.

## Center-of-glass values of laminated glazing.



# Surface Treatments

- Surface treatments for glazing layers/panes is comprised of the following:
  - Frit Glass
  - Acid-Etched and Sandblasted Glass

# Frit Glass

- Silk-screening ceramic frit onto glass enables the designer to use color and patterns on architectural glazing.
- Combined with clear or tinted glass substrates, as well as high-performance coatings, fritted glazing can help reduce solar heat gain.
- An opaque frit pattern can help control glare but translucent frit patterns may provide diffuse light that increases glare.

# Ceramic Frit Paint

- Ceramic frit paint is comprised of minute glass particles, pigment, and a medium to mix the glass and pigment together.
- The paint is applied to one side of the glass—either heat-strengthened or fully tempered to prevent glass breakage due to thermal stresses under sunlit applications—and is fired in a tempering furnace to create a permanent coating.

# Frits & IGUs

- For an insulating glass unit, the silk screen pattern is ideally located within the sealed cavity for protection.
- Frit can also be applied to laminated glass units.
- A low-E coating can be placed on top of the frit. To reduce long-wave radiative heat gains, it is best to use the fritted layer on the interior surface of the exterior pane of an insulating glass unit.

# Frits

- White ceramic frit has been the predominant color, however, dark ceramic frits, such as neutral gray, black, and silver metallic are increasingly utilized.
- These colors also help reduce reflection and offer alternative design options without adversely affecting performance.
- Frit location—or multiple frit combinations—within a glazing assembly affect such factors as solar absorption, shading coefficient, and appearance.

# Design Flexibility

- The design flexibility—in terms of pattern and color—of fritted glass is appealing, but many manufacturers also offer standard patterns, such as dots, lines, and holes.
- Pattern coverage is specified, most often in the 40 to 60% range, with density naturally impacting glass performance characteristics and vision area.
- In practice, the SHGC of a frit coating is affected by its color and location in the window assembly.

# Acid-Etched & Sandblasted Glass

- Acid etching gives a matte finish to glass panes, with the degree of finish being determined by the length of time the acid is in contact with the surface.
- By masking, patterns and pictures can be etched into the glass to give the architect design flexibility. An intense etching process roughens the glass surface, which diminishes transparency.
- Light passing through the glass is scattered to obscure view and diffuse light. Glass can also be sandblasted to give a similar matte finish.
- It should be noted that diffusing glass can sometimes increase glare since surface brightness is increased.

# Detailed View of Frit Glazing



# Applied Films

- Solar control window film reduces solar heat gain by reflection and absorption. As they also block solar heat gain in winter months, these films are ideal for cooling-dominated climates.
- Window films can be tinted for solar heat and glare control, but some recent window film options reflect solar heat while maintaining a relatively clear appearance.

# Certified Products Directory

- The lower a film's solar heat gain coefficient (SHGC), the less solar heat it transmits.
- The higher the visible transmittance (VT) number, the more light is transmitted.
- Window film does not provide substantial insulating benefits. To find certified window films, visit the NFRC's [Certified Products Directory](#).

# Thermal Stress

- Window film often is applied to the room-side glass surface of windows. Since window film absorbs the portion of solar heat that it does not reflect or transmit, it increases the glass temperature and may cause thermal stress on the glass or insulated glazing seals, particularly on sunny but cold days.
- Before installing window film, be sure to check whether this interferes with the warranty conditions for your windows and whether self-installation would meet the window film's warranty requirements.

# Window Film Information Center

- Before having window film installed, it is advisable to have a window film professional check your windows' location, type and condition to match the appropriate film to the glass type.
- For more information on the factors to take into account when installing window film, check the [Window Film Information Center](#) by the International Window Film Association.

# Window & IGU Assembly

- Is primarily comprised of the following:
  - Assembly of Glazing Layers
  - Gas Fills
  - Spacers
  - Frames
  - Air Leakage

# Assembling Glazing Layers

- One of the shortcomings of glass is its relatively poor insulating qualities.
- Multiple panes of glass with air spaces in between improve the insulating value considerably (see figure to the right).
- Relative to all other glazing options, clear single glazing allows the highest transfer of solar energy while permitting the highest daylight transmission.

# Low-E & Gas Fill

- Double glazing reduces heat loss (as reflected by the U-factor) by more than 50% in comparison to single glazing.
- Although U-factor is reduced significantly, the VT and SHGC for a double-glazed unit with clear glass remain relatively high.
- Adding a [low-E coating](#) to a surface of the double-pane unit will increase the energy performance. Depending on the type of low-E coating, the SHGC and VT will also be affected.
- Adding a [gas fill](#) between the layers of glass will also improve energy performance.

# Physical & Economic Limits

- Additional panes of glass increase the weight and thickness of the unit, which makes mounting and handling more difficult and transportation more expensive.
- There are physical and economic limits to the number of glass panes that can be added to a window assembly.
- However, multiple-pane units are not limited to glass assemblies.

# Suspended Films

- The middle layer(s) of glass can be substituted with an inner plastic suspended film (see figures below).
- The light weight of plastic film is advantageous, and because it is very thin, does not increase the unit thickness. Windows using plastic films decrease the U-factor of the unit assembly by dividing the inner air space into multiple chambers.
- When protected by glass panes from scratching, wear, weathering, and visual distortions caused by wind, the limited strength and durability of the plastic film is overcome.

# Multiple Panes & Plastic Films

- The plastic films are specially treated to resist UV degradation and are heat shrunk so they remain taut and flat. Like glass, a low-E coating can be bonded to the plastic film to lower the assembly U-factor.
- The plastic film can also be treated with spectrally selective coatings to reduce solar gain in hot climates without significant loss of visible transmittance. The low-E coatings can be applied to the glass or plastic.
- The combination of multiple glass panes and plastic films with low-E coatings and gas fills achieves very low center-of-glass U-factors—as low as 0.08.

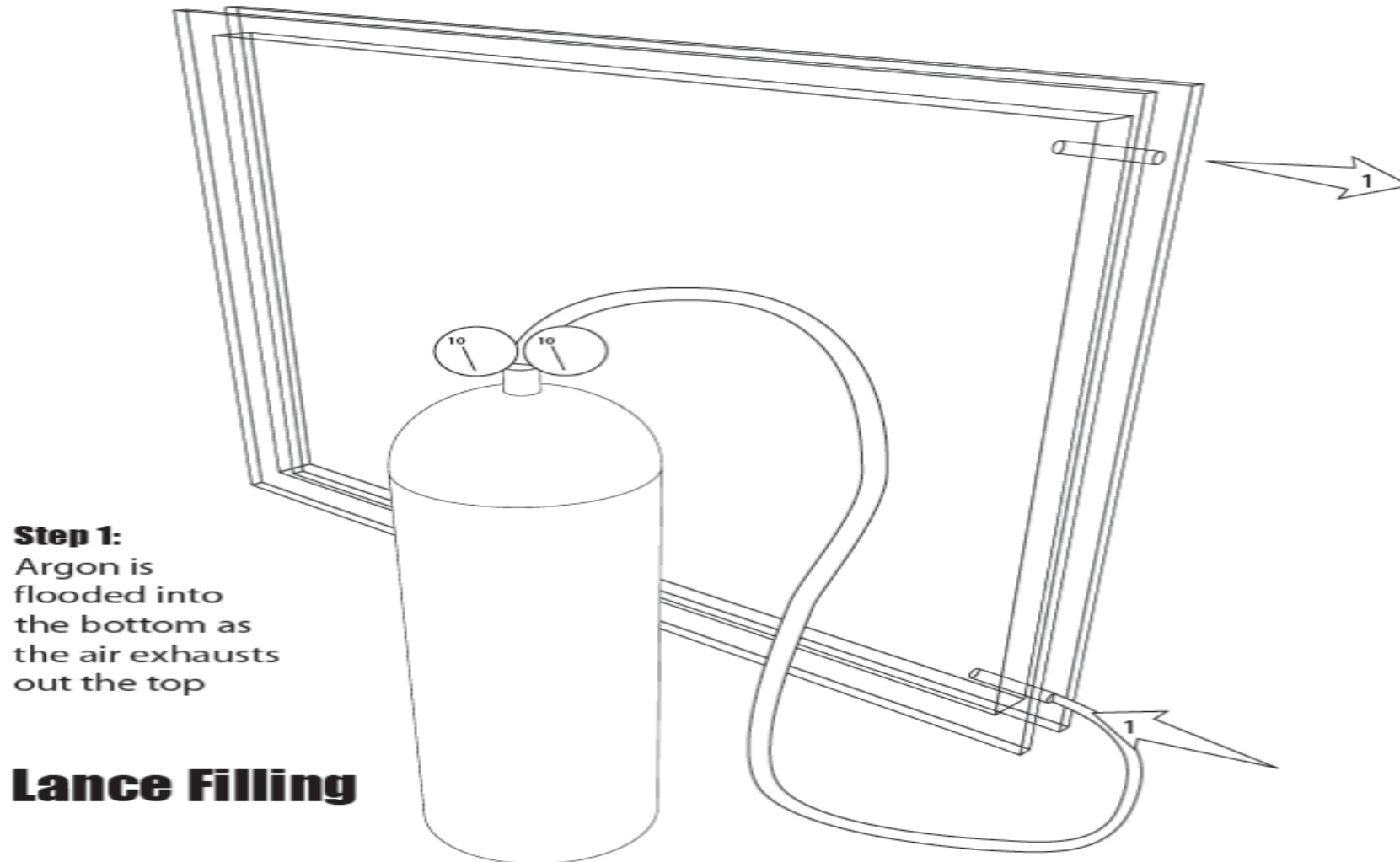
# Gas Fills

- As higher-performance commercial facades are developed, the use of low-conductance gas fills becomes more common.
- Gas fills improve the thermal performance of insulating glazing units by reducing the conductance of the air space between the layers.
- Originally, the space was filled with air or flushed with dry nitrogen just prior to sealing.

# Sealed Glass Insulating Units

- In a sealed-glass insulating unit, air currents between the two panes of glazing carry heat to the top of the unit along the inner pane and settle down the outer pane into cold pools at the bottom.
- Filling the space with a less conductive, more viscous, or slow-moving gas minimizes the convection currents within the space, reducing conduction through the gas and the overall heat transfer between the interior and exterior.

# Gas Filling Techniques



# Two Hole Filling Method

- Because we cannot see air and argon, it can be difficult to comprehend how gas filling of insulating glass is done. The traditional two hole filling concept is really quite simple. Argon is about forty percent heavier than air. For a short period of time air will actually float on top of argon.
- By carefully introducing argon at the bottom of an insulating glass unit, it is possible to float the air up and out the top. The key ingredient being this careful introduction of the argon.

# One Hole Filling Method

- One-hole filling methods have now been developed. If argon is turbulently introduced this lamination will not occur. The window must then be filled by stirring in large amounts of argon and eventually diluting the mixture of air and argon to mostly argon.
- The goal of one hole filling is to stir the gas into the cavity as turbulently as possible. This violent introduction of gas is accompanied by a rapid evacuation of the air needing to be removed, assisted by the vacuum pump. The turbulent exchange of incoming gas and outgoing air is continued until the conductivity sensor has determined the evacuated air / gas mixture has reached the preset shut off point.

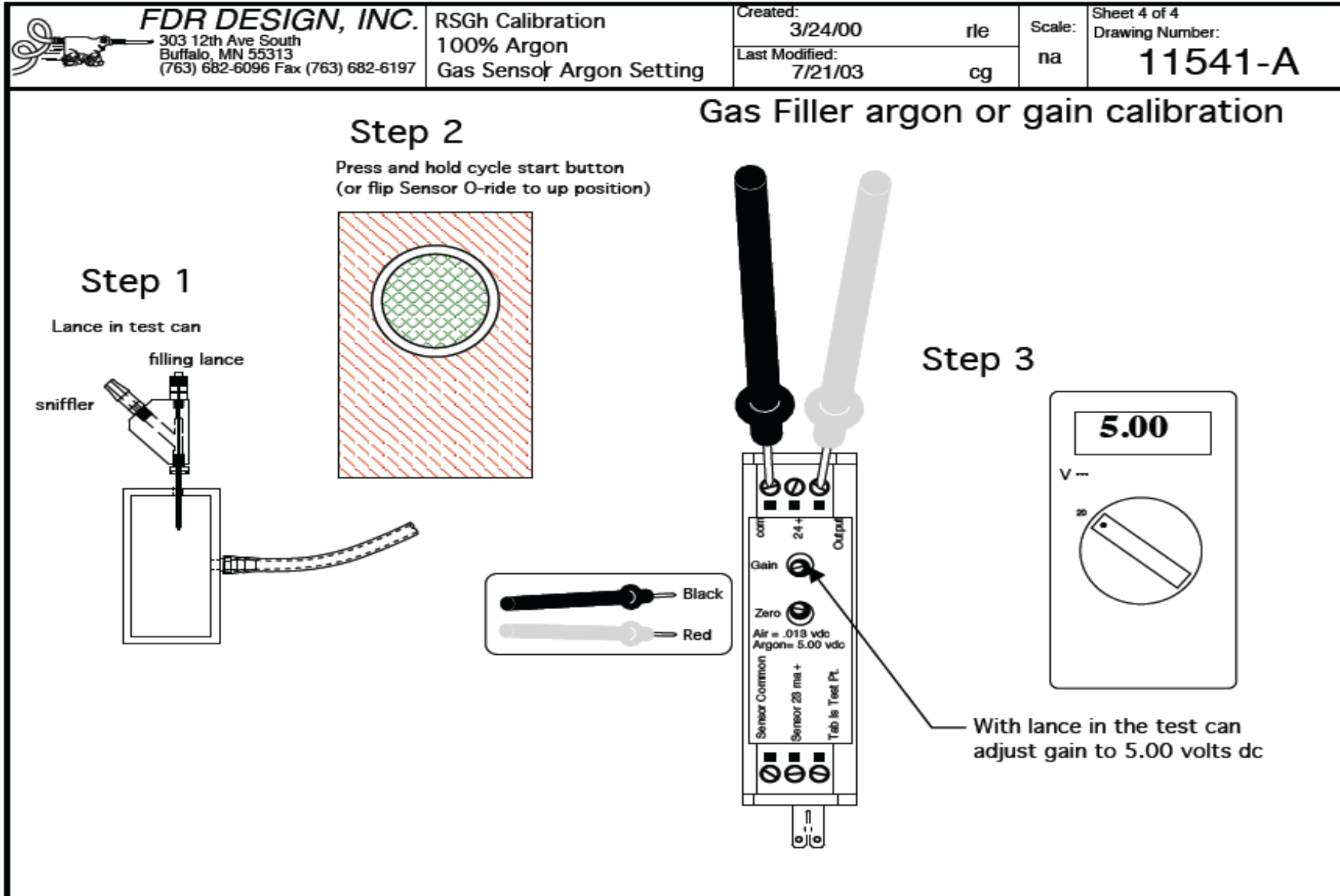
# Typical One Hole Filling Speed

- Flow rate: 15 - 28 liters per minute (argon), per line. Normally the gas filling machine is set to yield 95% ( $\pm 2$ ) fill rates for two hole filling and 92% ( $\pm 2$ ) fill rates for one hole filling.
- The machine can also be adjusted for various filling percentages by adjusting the calibration voltage on the gas sensor amplifier board.
- Fill rates are largely dependent on the operator's skill and unit construction.

# Gas Fill Techniques

- Because one hole filling was designed with the purpose of having only one hole in the spacer, relative efficiency was not a concern.
- The total volume of gas in the IG will be replaced 3 to 4 times to obtain  $>90\%$  fill, as compared with 2 to 3 times for the two hole filling method.
- For this reason, it is not advised to use the one hole filling method with more expensive and exotic gases like krypton or xenon.

# FDR Design Gas Fill Equipment



# Argon Gas Fills

- Argon, however, is relatively inexpensive, and while the spent gas is still an expense, less labor is required as only one hole in the spacer has to be sealed.
- The term “Turns” is used to define how many times the volume of gas in the IG has been turned over, or replaced.
- Once the window is filled and sealed a minute amount of gas will gradually seep out of the unit, not only from the top, but from all sides.
- The gas, as it dilutes over time, will not be of different concentrations moving from the top to the bottom of the window, but rather completely mixed together.
- If the window is ninety percent argon and ten percent air, this same concentration is present everywhere in the cavity.

# Argon & Krypton

- Manufacturers generally use argon or krypton gas fills, with measurable improvement in thermal performance.
- Both gases are inert, nontoxic, nonreactive, clear, and odorless.
- Krypton has better thermal performance than argon, but is more expensive to produce.

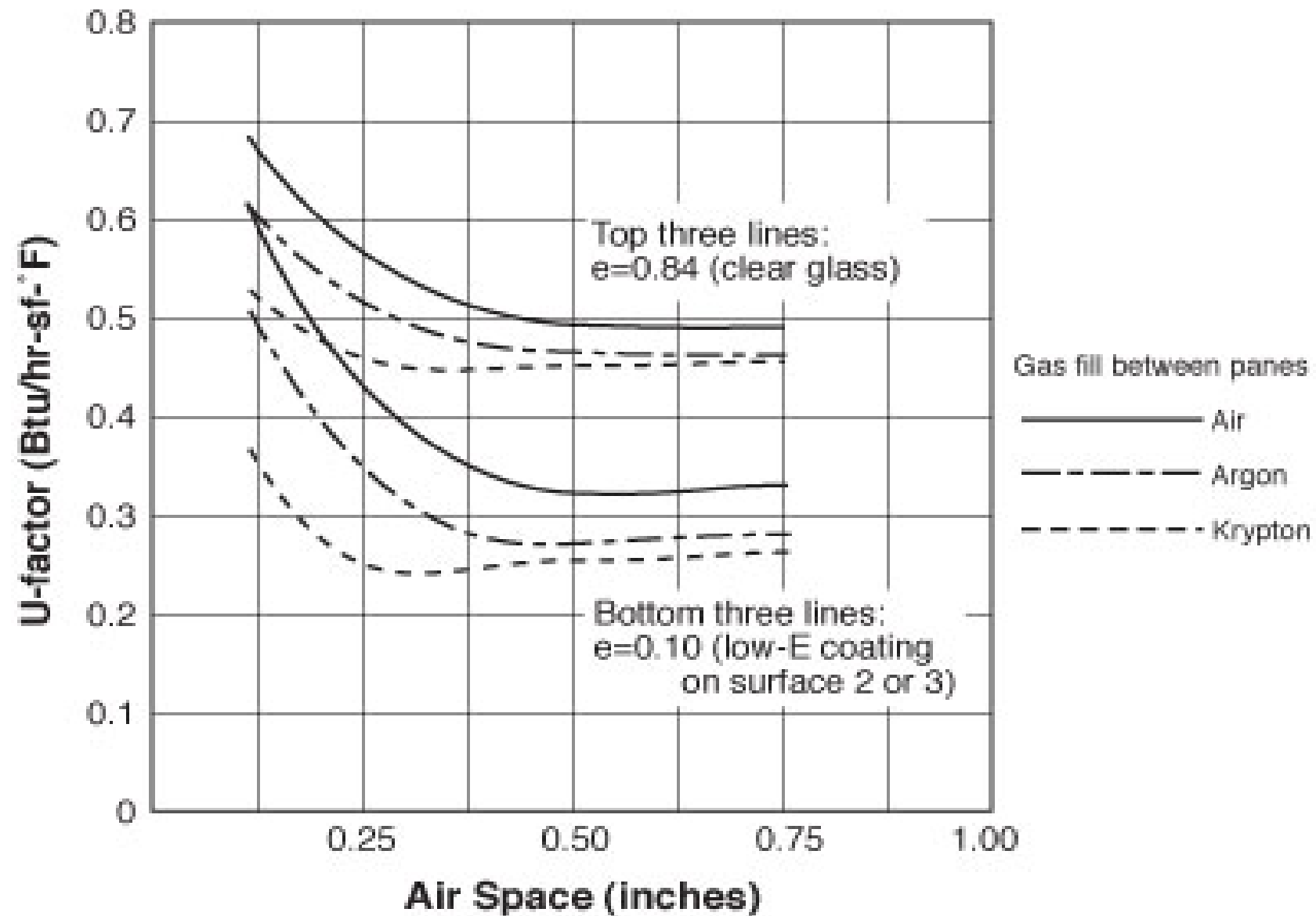
# Gap Spacing

- The optimal spacing for an argon-filled unit is the same as for air, 0.5 to 0.65 inches.
- Krypton is particularly useful when the space between glazings must be thinner than normally desired, for example, 0.25 to 0.41 inches.
- A mixture of krypton and argon gases is also used as a compromise between thermal performance and cost.

# Preventing Gas Leakage

- Argon and krypton occur naturally in the atmosphere, but maintaining long-term thermal performance is certainly an issue.
- Studies have shown less than 0.5% leakage per year in a well-designed and well-fabricated unit, or a 10% loss in total gas over a twenty-year period.
- The effect of a 10% gas loss would only be a few percent change in U-factor on an overall product basis.
- Keeping the gas within the glazing unit depends largely upon the quality of the design, materials, and, most important, assembly of the glazing unit seals.

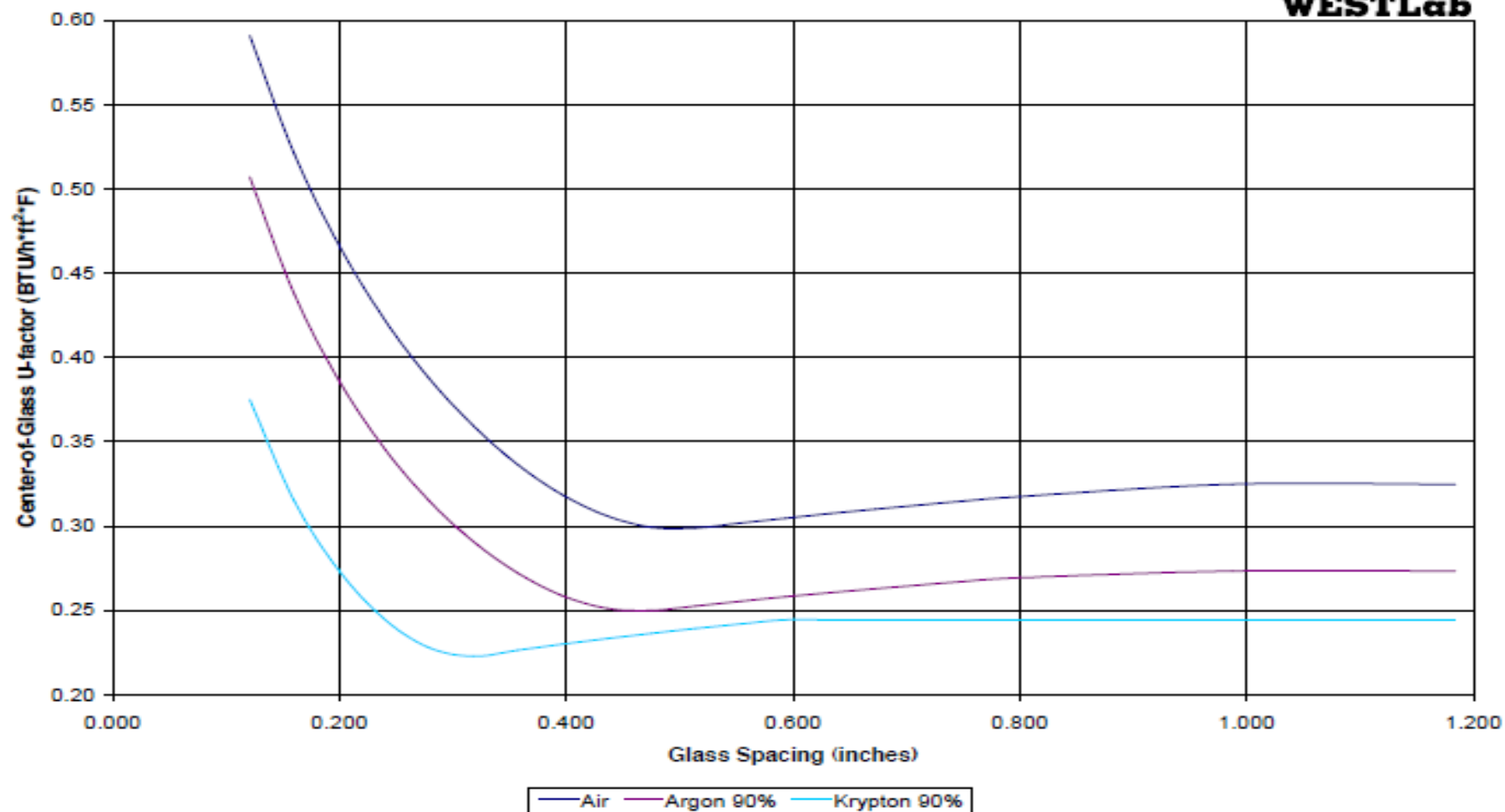
## U-factor as a function of air-space thickness and emittance.



# Simulations

**Center-of-Glass U-factor (IP) vs. Glass Spacing**  
**Double Glazed Low-e 0.04 Argon and Krypton Fills**  
Gas percentages represent initial fill rates achieved, balance assumed to be air.  
Calculations performed using Window 5.2 computer program by WESTLab.

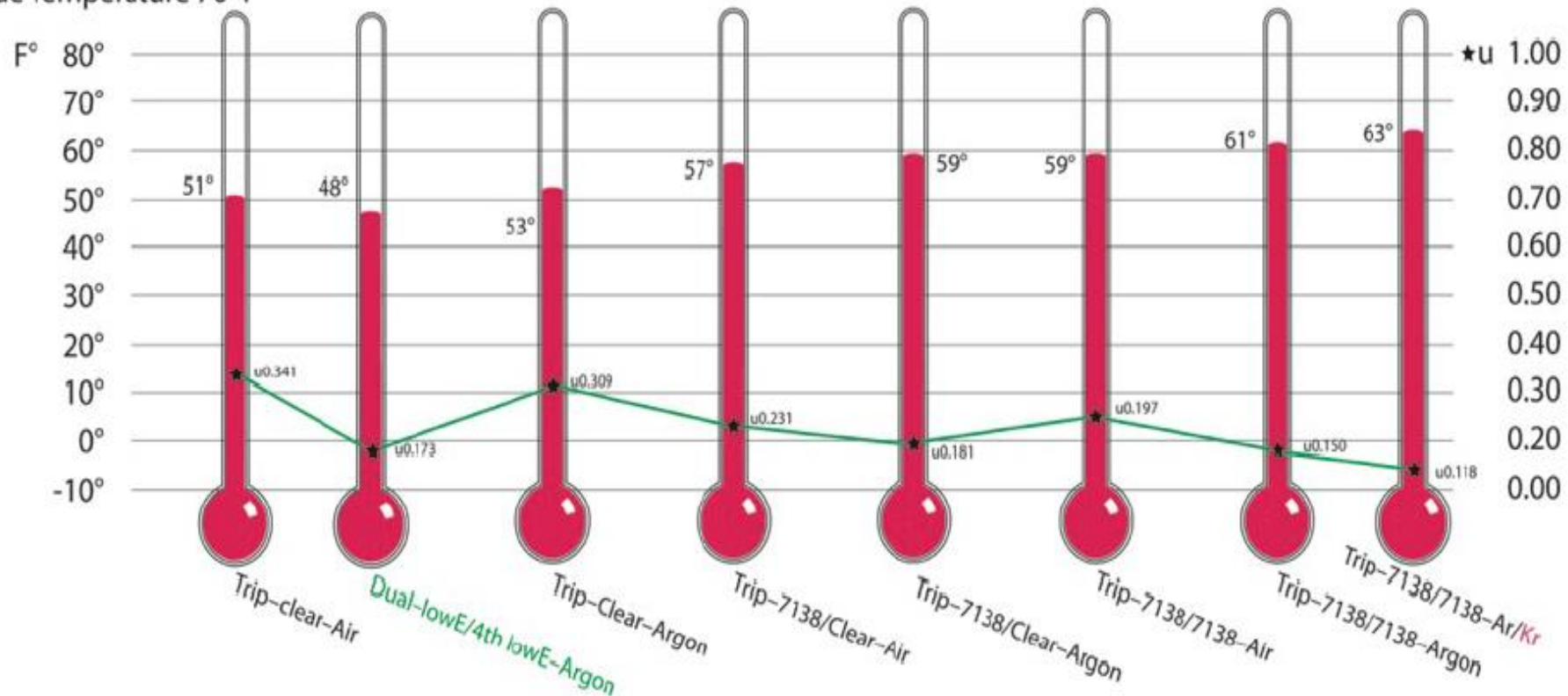
work sponsored  
**FDR Design, Inc.**  
**SPECTRA GASES**  
**WESTLab**



# Comfort

## Surface Temperature of Glass

Outside Temperature 0° F  
Inside Temperature 70° F



# Optimal Gap Thickness

- Based on the above chart and Window 7 modeling software, the optimal gap thickness of IGUs using Low-e coatings for multiple pane IGUs can be determined for air and each inert gas utilized, e.g., primarily argon and krypton.
- Determining optimal gap thickness for gas-air mixtures such as 10% air and 90% argon or 12% air, 22% argon and 66% krypton may provide the most economical approach for low-e glazing systems.

# Air & Gas Mixture Conductivity

- Measured in units of Btu/hr-ft<sup>2</sup>-°F
  - Pure Air = 0.013907
  - 10% Air, 90% Argon = 0.009858
  - 5% Air, 95% Argon = 0.009651
  - Vacuum Air P=0.001 (conductance) = 0.009602
  - Pure Argon = 0.009446
  - 12% Air, 22% Argon, 66% Krypton = 0.006639
  - Pure Krypton = 0.005005
  - Pure Xenon = 0.002981

(data obtained from Window 7 modeling software)

# **Optimal Air/Gas Mix & Gap Thickness**

- Based on the above conductivity values and costs for argon and krypton, mixtures of these gases would probably provide the best cost benefits for various low-e glass configurations.
- Using LBNL Window software, modeling should be conducted to determine the optimal gap thickness and the cost benefit from each insulated glass configuration.

# Edge Spacer Technology

- The lites of glass in an insulating unit must be held apart at the appropriate distance by spacers. In addition to keeping the glass lites separated, the spacer system must serve a number of functions:
  - accommodate stress induced by thermal expansion and pressure differences;
  - provide a moisture barrier that prevents passage of water or water vapor that would fog the unit;
  - provide a gas-tight seal that prevents the loss of any special low-conductance gas in the air space;
  - create an insulating barrier that reduces the formation of interior condensation at the edge.

# Spacers & Sealants

- The standard solution for insulating glass units (IGUs) is the use of metal spacers and sealants.
- These spacers, typically aluminum, also contain a desiccant that adsorbs residual moisture.
- The spacer is sealed to the glass lites with organic sealants that provide structural support and act as a moisture barrier.

# Single & Dual Spacer Systems

- There are two generic systems for such IGUs: a single-seal spacer and a dual-seal system.
- In the single-seal system, an organic sealant, typically a butyl-based material, is applied behind the spacer and serves to hold the unit together and prevent moisture intrusion.
- These seals are normally not adequate to contain special low-conductance gases.

# Dual Spacer Systems

- In a dual-seal system, a primary sealant, typically PIB (Polyisobutylene), seals the spacer to the glass to prevent moisture migration and gas loss, and a secondary backing sealant, often silicone, provides structural strength.
- When [sputtered low-E coatings](#) are used with dual-seal systems, the coating is typically removed from the edge first (edge deletion) to eliminate the potential for coating corrosion that may lead to premature IG failure.

# Warm Edge Spacers

- Since aluminum is an excellent heat conductor, the aluminum spacer used in most standard edge systems represents a significant thermal "short circuit" at the IGU edge, reducing the benefits of improved glazings.
- Component manufacturers have developed a series of innovative edge systems to address this problem, including solutions that depend on material substitutions as well as radical new designs and are collectively known as "warm-edge" spacers.
- One approach to reducing heat loss replaces the aluminum spacer with a less conductive metal, e.g., coated stainless steel, and changing the cross-sectional shape of the spacer.

# Insulating Silicone Foam Spacers

- Another approach is to replace the metal with a design that uses better insulating materials.
- An example is an insulating silicone foam spacer that incorporates a desiccant and has a high-strength adhesive at its edges to bond to glass that has now been in use for over 15 years.
- The foam is backed with a secondary sealant.
- Both extruded vinyl and pultruded fiberglass spacers have also been used in place of metal designs.

# High-Performance Glazing

- Warm edge spacers have become increasingly important as manufacturers switch from conventional double glazing to higher-performance glazing.
- For purposes of determining the overall window U-factor, the edge spacer has a thermal effect that extends beyond the physical size of the spacer to a band about 2-½ inches wide.
- The contribution of this 2-½-inch-wide "edge of glass" to the total window U-factor depends on the size of the window. For instance, edge of glass effects are more important for smaller windows, which have a proportionately larger glass edge area.

# Multiple Layer Windows

- A more significant benefit may be the rise in interior surface temperature at the bottom edge of the window, which is most subject to condensation.
- With an outside temperature of 0° F, a "warm-edge" spacer could result in temperature increases of up to 18° F at the window sightline or 9° F at a point one inch in from the sightline as compared to an aluminum spacer.
- As new highly insulating multiple layer windows are developed, the improved edge spacer becomes an even more important element.

# Thermal Imaging of Windows

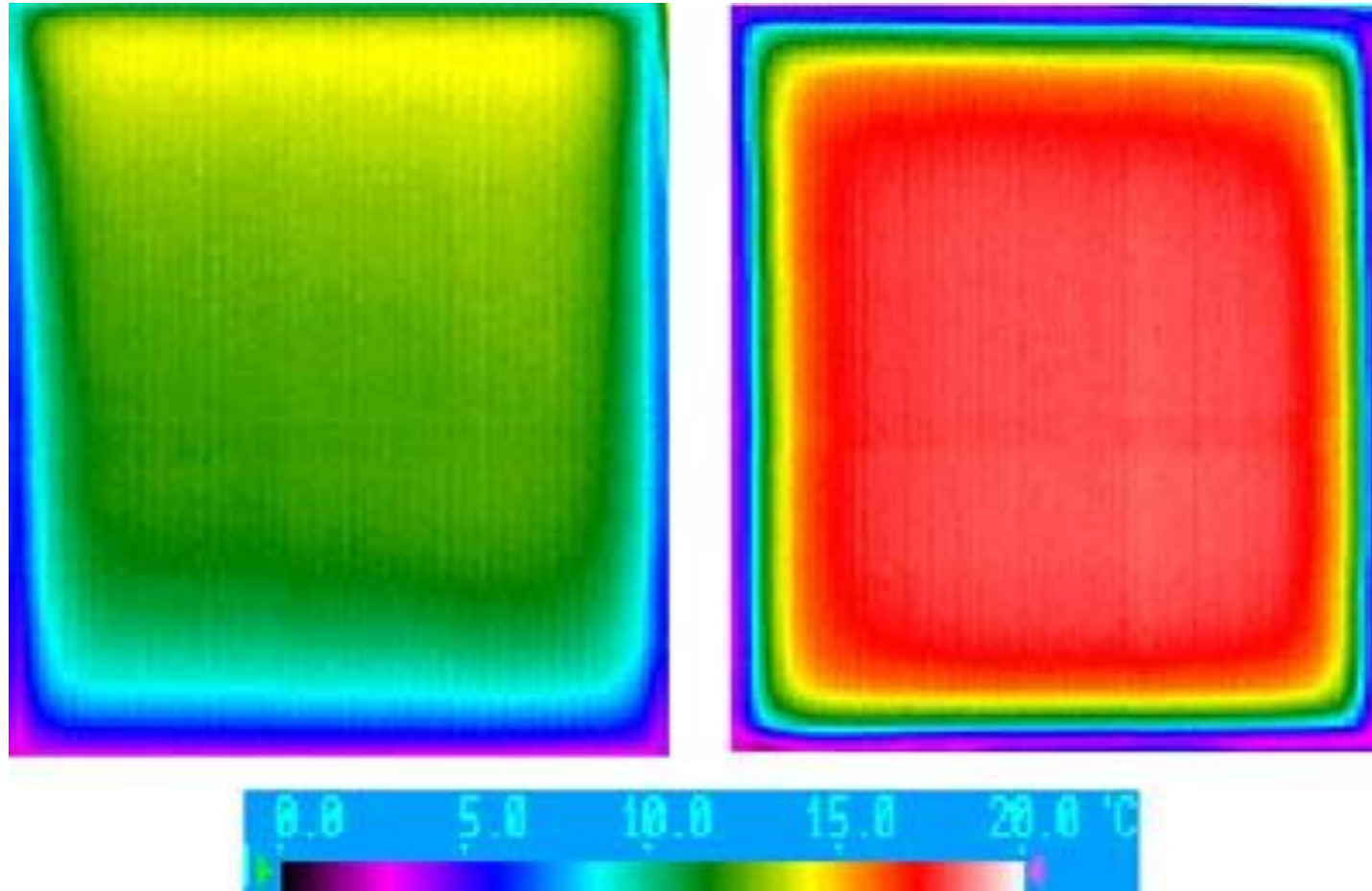
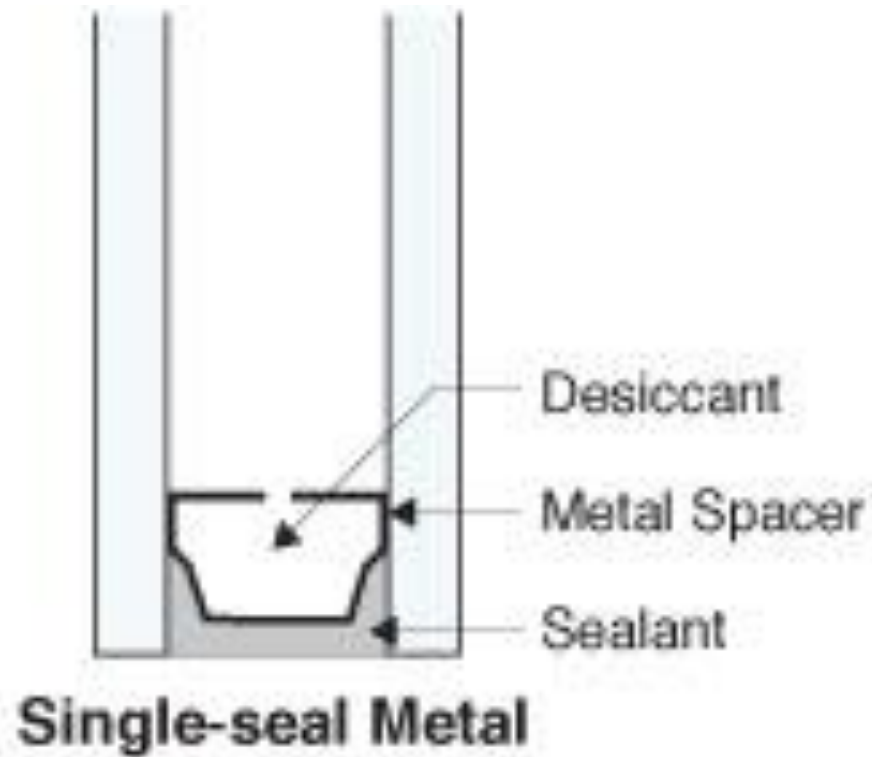


Image courtesy Lawrence Berkeley National Laboratory

# Thermal Imaging of Windows cont.

- The window on the left is a double glazing with low-E and an insulating spacer.
- The window on right also uses low-E and a partially insulating spacer.
- The difference is that on the right the window uses three different low-E coatings in a quadruple layer design and the air inside the panes has been replaced with more insulating krypton gas.
- Such a high performance window is called a "superwindow". These windows are being cooled on the back side with wind at -17.8°C (0°F).

# Various metal and non-metal spacer systems



# Types of Window Frames

- The material used to manufacture the window frame governs the physical characteristics of the window, such as frame thickness, structural concerns, weight, and durability, but it also has an impact on the thermal characteristics of the window.
- Manufacturers are beginning to produce hybrid or composite sash and frame units, in which multiple materials are selected and combined to best meet the overall required performance parameters.

# Whole Window U-factor

- While it is useful to understand the role that frame type plays in window thermal performance, the frame U-factor is not normally reported by manufacturers.
- The window U-factor, as given on an NFRC certified rating or label, incorporates the thermal properties of both the frame and the glazing.
- The remainder of this section describes aluminum, wood, and vinyl frames, and introduces some new frame materials that are commercially available.

# Aluminum Frames

- Light, strong, durable, noncorrosive, and easily extruded into the complex shapes required for window parts, aluminum can be fabricated to extremely close tolerances to create special forms for the insertion of glazing, weatherstripping, and thermal breaks.
- Aluminum frames are available in anodized and factory-applied high-performance painted finishes that are extremely durable and low-maintenance.

# Aluminum Frames cont.

- The biggest disadvantage of aluminum as a window frame material is its high thermal conductance, which raises the overall U-factor of a window unit.
- Because of this, the thermal resistance of an aluminum frame is determined more by the surface area of the frame than by the thickness or projected area, as with other frame materials.
- Thus, an aluminum frame profile with a simple, compact shape will perform better than a profile with many fins and undulations.

# Aluminum Frames cont.

- In cold climates, a non-thermally broken aluminum frame can easily become cold enough to condense moisture or frost on the inside surfaces of window frames.
- Even more than the issue of heat loss, condensation problems have spurred development of better insulating aluminum frames. The most common solution to the heat conduction and condensation problem of aluminum frames is to provide a thermal break by splitting the frame components into interior and exterior pieces, which are joined by a less conductive material.
- There are many designs available for thermally broken aluminum frames.

# Aluminum Frames cont.

- Current technology with standard thermal breaks has improved aluminum frame U-factors from roughly 2.0 to about 1.0.
- Innovative new thermal break designs have been combined with changes in frame design to achieve U-factors lower than 0.5, but at a higher cost than current thermally broken frames.
- Where controlling solar gain is often more important than reducing conductive heat transfer, improving the insulating value of the frame is less important than using a solar control glazing system.

# Wood Frames

- Wood is a traditional window frame material because it is widely available and easy to mill into the complex shapes required to make windows.
- Wood is not intrinsically the most durable window frame material because of its susceptibility to rot and its high maintenance requirements, but well-built and well-maintained wood windows can have a very long life.

## **Wood Frames cont.**

- Cladding the exterior face of a wood frame with either vinyl or aluminum creates a permanent weather-resistant surface.
- Clad frames thus have lower maintenance requirements, but retain the attractive wood finish on the interior.

## Wood Frames cont.

- From a thermal point of view, wood-framed windows perform well, with frame U-factors in the range of 0.3 to 0.5 Btu/hr-sq ft-°F.
- The thicker the wood frame, the more insulation it provides.
- However, metal cladding, metal hardware, or the metal reinforcing often used at corner joints can lower the thermal performance of wood frames.

# Vinyl Frames

- Vinyl, also known as polyvinyl chloride (PVC), is a very versatile plastic with good insulating value, high impact resistance, and good resistance to abrasion.
- Because its color runs all the way through the material, there is no finish coat that can be damaged or deteriorate over time.
- Recent advances have improved PVC's dimensional stability and resistance to degradation from sunlight and temperature extremes.

# Vinyl Frames cont.

- Similar to aluminum windows, vinyl windows are fabricated by cutting standard lineal extrusions to size and assembling the pieces into complete sash and frame elements.
- Vinyl window frames require very little maintenance, do not require painting, and have good moisture resistance.
- To provide the required structural performance, vinyl sections are often larger than aluminum window sections, with sizes closer to the dimensions of wood frame sections. Larger vinyl units will often need to incorporate metal or wood stiffeners.

# Vinyl Frames cont.

- Since vinyl has a higher coefficient of expansion than either wood or aluminum, vinyl window frame profiles should be designed and assembled to eliminate excessive movement caused by thermal cycles.
- In terms of thermal performance, most vinyl frames are comparable to wood. Large hollow chambers within the frame can allow unwanted heat transfer through convection currents. Creating smaller cells within the frame reduces this convection exchange.
- Vinyl frames can also be insulated—the hollow cavities of the frame filled with insulation—making them thermally superior to standard vinyl and wood frames.

# Hybrid Frames

- Manufacturers have begun marketing hybrid frame designs that use two or more of the frame materials described above to produce a complete window frame system.
- The wood industry has long built vinyl- and aluminum-clad windows to reduce exterior maintenance needs.
- Vinyl manufacturers offer interior wood veneers to produce the appearance of wood, and split-sash designs may have an interior wood element with an exterior vinyl or fiberglass element.

# Wood/Polymer Composites

- Most people are familiar with composite wood products, such as particle board and laminated strand lumber, in which wood particles and resins are compressed to form a strong composite material.
- The window industry has taken this technology a step further by creating a new generation of wood/polymer composites that are extruded into a series of lineal shapes for window frame and sash members.
- These composites are very stable, and are comparable to or exceed the structural and thermal properties of conventional wood, with better moisture resistance and more decay resistance.

# Fiberglass Pultrusions

- Window frames can be made of either glass-fiber-reinforced polyester or fiberglass, which is pultruded into lineal forms and then assembled into windows.
- Such frames are dimensionally stable and achieve good insulating value by incorporating air cavities (similar to vinyl). Like vinyl, the cavities can be filled with insulation for higher thermal performance.

# Fiberglass Pultrusions cont.

- The strength of fiberglass allows manufacturers to maintain the same sight lines as aluminum windows while achieving significantly lower U-factors. The low coefficient of thermal expansion maintains seal integrity and minimizes warpage or leakage in high inside/outside temperature differentials.
- Fiberglass pultrusions have a higher heat deflection temperature than vinyl, permitting the use of dark colors unlike other thermoplastic extrusions. They can be painted, powder coated, or finished with coextruded acrylic resin.

# Engineered Thermoplastics

- Another alternative to vinyl is extruded engineered thermoplastics, a family of plastics used extensively in automobiles and appliances.
- Like fiberglass, they have some structural and other advantages over vinyl but are also more expensive and have not yet captured a large market share.

# Hybrid Window Frames

- By combining the strength and versatility of aluminum and thermal break technology, or going with the relatively low conductivity of insulated fiberglass for exteriors of hybrid frames, can potentially provide a low maintenance and low cost window frame solution.
- Foam layers on the inside of the frame covered with wood or wood/polymer composite interiors may allow for achieving unprecedented thermal resistance, possibly allowing for total window U-values approaching R-16 via state-of-the-art IGUs described above.

# Hybrid Frame with Wood Interior



# Insulated Fiberglass Frame



# Foam-Wood Thermal Breaks

- Hybrid window frames can be developed by merely adding a radiant glass low-e pane and finishing the frame with foam and wood or wood/polymer composites to optimize thermal resistance.
- Natural wood products or wood polymers can be used in conjunction with foam as a thermal break for aluminum, foam-filled fiberglass, or foam-filled thermoplastics and vinyl to achieve optimal thermal resistance while providing a beautiful wood finished interior combined with durable low maintenance exteriors.

# Air Leakage (Infiltration)

- Whenever there is a pressure difference between the inside and outside (driven by wind or temperature difference), air will flow through cracks between window assembly components.
- The air leakage properties of window systems contribute to the overall building air infiltration.
- Infiltration leads to increased heating or cooling loads when the outdoor air entering the building needs to be heated or cooled.

# Weatherstripping

- Air leakage also contributes to summer cooling loads by raising the interior humidity level.
- Operable windows can be responsible for air leakage between sash and frame elements as well as at the window/wall joint.
- Tight sealing and weatherstripping of windows, sashes, and frames is of paramount importance in controlling air leakage.

# Fixed Picture Windows

- The use of fixed windows helps to reduce air leakage because these windows are easier to seal and keep tight.
- Operable windows, which are also more susceptible to air leakage, are not necessary for ventilation in most commercial buildings but are desired by occupants for control.
- Operable window units with low air-leakage rates feature mechanical closures that positively clamp the window shut against the wind.

# Compression-seal Windows

- For this reason, compression-seal windows such as awning, hopper, and casement designs are generally more effectively weatherstripped than are sliding-seal windows.
- Sliding windows rely on wiper-type weatherstripping, which is more subject to wear over time.

# Proper Installation

- The level of infiltration depends upon local climate conditions, particularly wind conditions and microclimates surrounding the building.
- In reality, infiltration varies widely with wind-driven and temperature-driven pressure changes.
- Cracks and air spaces left in the window assembly can also account for considerable infiltration.
- Insulating and sealing these areas during construction can be very important in controlling air leakage.
- A proper installation ensures that the main air barrier of the wall construction is effectively sealed to the window or skylight assembly so that continuity of the air barrier is maintained.

# Causes of Window Infiltration

- Infiltration (and exfiltration) occurs due to three factors:
  - poor product design
  - poor quality control during product manufacturing
  - poor construction detailing and/or installation
- Test procedures, such as ASTM E283-04 Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen, are used widely in the industry to account for product design, and to some extent, quality control.

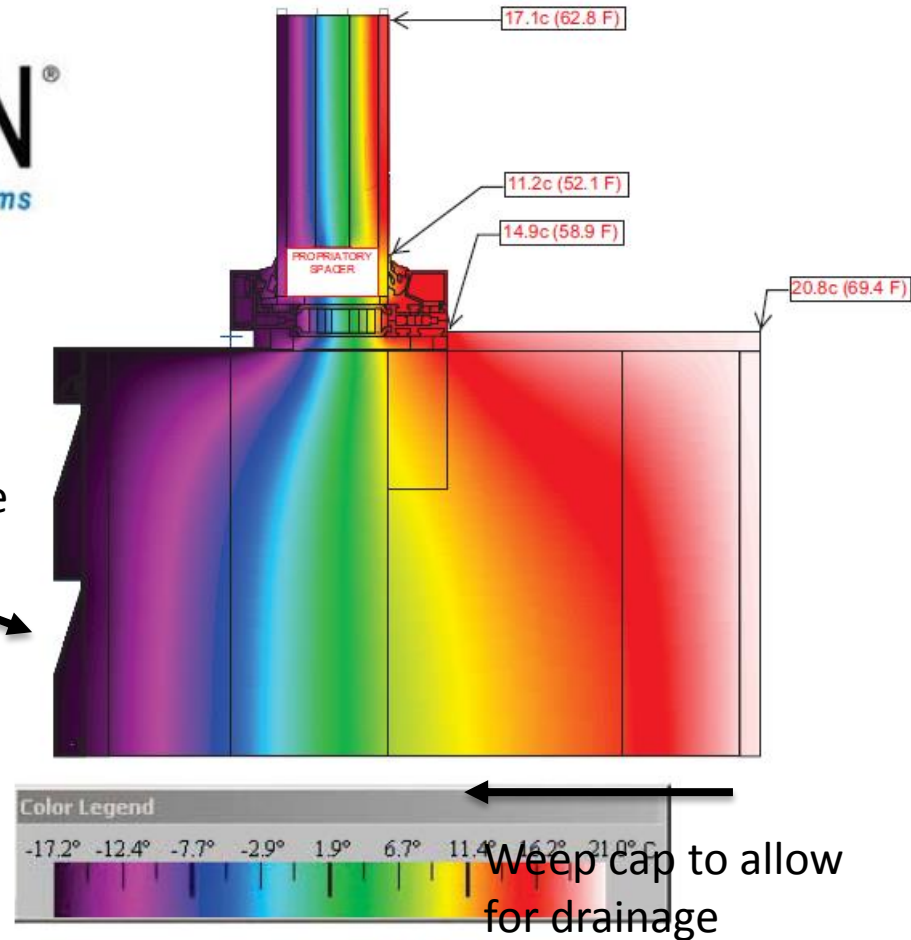
# Foam Installation

- For ICF exterior walls, foam can replace wood for installation of high performance super insulated windows.
- This allows for achieving unprecedented thermal resistance and high performance for the entire window system.
- In addition to EPS foam, metal brackets and clips are inserted into the concrete cavity, extending up through the foam and used to fasten to the window frame.

# LBNL Therm 7 Infrared Image of ICF Foam Installation

**ENVISION**<sup>®</sup>  
High Performance Glazing Systems

Wood blocking for  
attaching window frame



# Quality Control

- Testing actual products off the production line at random will ensure that quality control is accounted for in infiltration test results.
- Infiltration due to poor construction detailing and/or installation can only be accounted for in test results if specific mock-ups of the wall section are designed and tested.

# Fenestration Standards

- AAMA/WDMA/CSA 101/I.S.2/A440, NAFS - North American Fenestration Standard/Specification for windows, doors, and skylights (Canadian supplement CSA A440S1-09) was developed for window, door, and skylight performance, including permissible air leakage.
- This specification is generally consistent with building codes used throughout the United States. Generally, operable products with an infiltration rate of less than 0.3 cfm/square foot are required.
- Architectural grade products utilizing a compression seal are required to have an infiltration rate of less than 0.1 cfm/square foot. Nonoperable products are not expected to have a measurable level of infiltration.

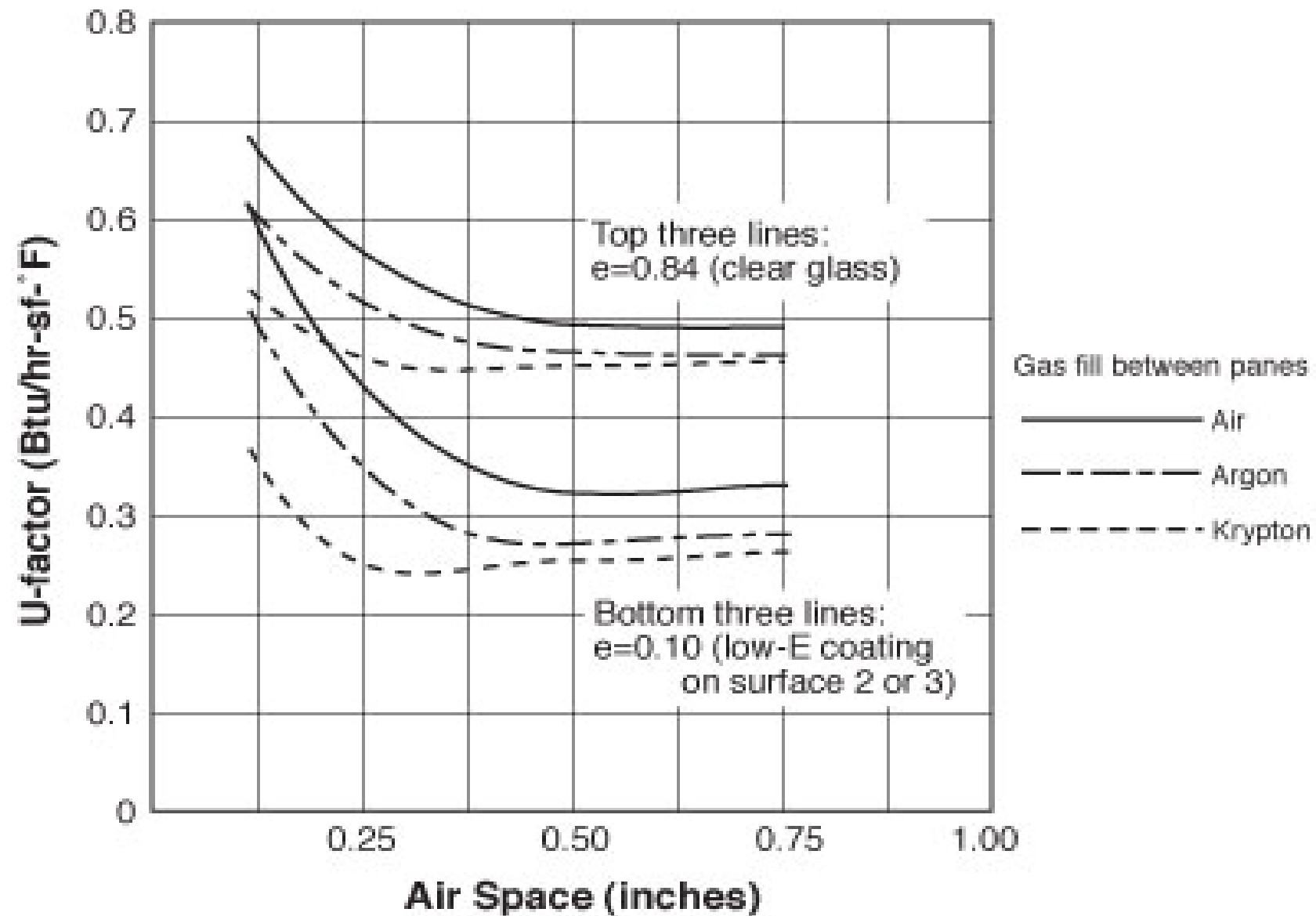
# Natural Ventilation

- The practice of operating windows to provide fresh air and cooling—is distinct from the issue of infiltration/exfiltration as it is based on the controlled movement of air through open windows.

# Focus Areas for Improvement

- Increasing performance and comfort while decreasing costs is key to the success of IGU and window manufacturing industries. Focus should be on:
  - Movement towards thicker IGUs and frames in order to increase performance while decreasing costs.
  - Provide better performing warm edge spacers, particularly for suspended coated films (SCF).
  - Providing hybrid frames with state-of-the-art thermal breaks in order to improve whole window U-values.

## U-factor as a function of air-space thickness and emittance.



# Optimal Gap Thickness

- Based on the above chart and Window 7 modeling software, the optimal gap thickness of IGUs using Low-e coatings for multiple pane IGUs can be determined for air and each inert gas utilized (e.g., primarily argon and krypton).
- Determining optimal gap thickness for gas-air mixtures such as 5% air and 95% argon or 12% air, 22% argon and 66% krypton may provide the most economical approach for low-e glazing systems.

# Air & Gas Mixture Conductivity

- Measured in units of Btu/hr-ft<sup>2</sup>-°F
  - Pure Air = 0.013907
  - 10% Air, 90% Argon = 0.009858 (-29%)
  - 5% Air, 95% Argon = 0.009651 (-31%)
  - Vacuum Air P=0.001 (conductance) = 0.009602 (-31%)
  - Pure Argon = 0.009446 (-32%)
  - 12% Air, 22% Argon, 66% Krypton = 0.006639 (-52%)
  - 5% Air, 95% Krypton = 0.005313 (-62%)
  - Pure Krypton = 0.005005 (-64%)
  - Pure Xenon = 0.002981 (-78%)

(data obtained from LBNL Window 7 modeling software)

# Increase in Thermal Resistance

– Pure Air	= 0.013907
– 10% Air, 90% Argon	= 0.009858 (140%)
– 5% Air, 95% Argon	= 0.009651 (144%)
– Vacuum Air P=0.001 (conductance)	= 0.009602 (145%)
– Pure Argon	= 0.009446 (147%)
– 12% Air, 22% Argon, 66% Krypton	= 0.006639 (209%)
– 5% Air, 95% Krypton	= 0.005313 (262%)
– Pure Krypton	= 0.005005 (278%)
– Pure Xenon	= 0.002981 (466%)

# Insulating Gas Leakage

- Noble gases, which are heavier and less conductive than air, can leak from efficient IGUs at a rate of about 0.05 to 1% per year.
- Depending on the type of spacers and seals utilized, this leakage can be minimized to less than 1% annually.
- Nevertheless, even with 1% leakage annually, the gas-filled gaps would lose only 18-19% and thus would still function substantially better than air.

# Insulating Gas Leakage

Year	Rare Gas Leakage Rate: 1% Annually		
	% Argon/Krypton	% Argon/Krypton	% Krypton
1	100	95	66
2	99	94.05	65.34
3	98.01	93.1095	64.86
4	97.0299	92.1784	64.04
5	96.0596	91.24103	63.44667
6	95.099	90.30523	62.79667
7	94.14801	89.36943	62.14667
8	93.20653	88.43363	61.49667
9	92.27447	87.49783	60.84667
10	91.35172	86.56203	60.19667
11	90.43821	85.62623	59.54667
12	89.53383	84.69043	58.89667
13	88.63849	83.75463	58.24667
14	87.7521	82.81883	57.59667
15	86.87458	81.88303	56.94667
16	86.00584	80.94723	56.29667
17	85.14578	80.01143	55.64667
18	84.29432	79.07563	54.99667
19	83.45138	78.13983	54.34667
20	82.61686	77.20403	53.69667
21	81.79069	76.26823	53.04667

# Insulating Gas Leakage

Year	Rare Gas Leakage Rate: 0.33% Annually		
	% Argon/Krypton	% Argon/Krypton	% Krypton
1	95.00	90.00	66.00
2	94.69	89.70	65.78
3	94.37	89.41	65.57
4	94.06	89.11	65.35
5	93.75	88.82	65.13
6	93.44	88.52	64.92
7	93.13	88.23	64.70
8	92.83	87.94	64.49
9	92.52	87.65	64.28
10	92.22	87.36	64.07
11	91.91	87.07	63.85
12	91.61	86.79	63.64
13	91.31	86.50	63.43
14	91.00	86.21	63.22
15	90.70	85.93	63.02
16	90.40	85.65	62.81
17	90.11	85.36	62.60
18	89.81	85.08	62.39
19	89.51	84.80	62.19
20	89.22	84.52	61.98
21	88.92	84.24	61.78

# State-of-the-Art Gas Fills

- FDR Design engineers and builds gas fill systems and equipment that can routinely achieve 0.33% annual gas loss.
- They recommend conservative estimates of initial gas fills of 95% with 2-4 turns (200-400% gas required to fill the chamber for 2 or 1 hole fills for Krypton and Argon, respectively).
- As indicated above, after twenty years a 95% gas fill would result in a gap with 88.92% of the original gas fill.

# Noble Gas Leakage cont.

- In comparison with 100% air, there is a 44% increase in thermal conductivity for 5% air-Argon or 5% air-Krypton.
- Based on losing 1% of 95% Argon/Krypton annually for 20 years, Argon/Krypton percentage would drop to ~77%, and 66% Krypton to ~54%.
- These decreases in gas levels represent only a 19% drop in thermal conductivity for 5% air-Argon/Krypton, and only an 18% drop in 66% Krypton over a twenty year period.
- In comparison with 100% air, there is a 110% increase in thermal conductivity for 12% Air, 22% Argon, and 66% Krypton; and 278% increase for 5% air-Krypton.

# Noble Gas Economics

- The 5% air-Argon and 12% air, 22% Argon and 66% Krypton gas mixtures offer the best cost benefits for use in windows.
- However, the 70 fold price increase in Krypton needs to continue to come down to be profitable for most window applications, except for perhaps the high end residential window industry where relatively small amounts of gases would increase costs by only  $\sim \$0.16/\text{f}^3$  (times 4 turns) for 5% air and 95% Argon;  $\sim \$6.76/\text{f}^3$  (times 2-4 turns) for 12% air, 22% Argon and 66% Krypton; and  $\$10.19/\text{f}^3$  (times 2 turns) for 5% air and 95% Krypton.

# Price of Gases per f<sup>2</sup> IGU

- Price for 95% Argon gas fill at 0.65 inch gaps would be \$0.00867 f<sup>2</sup> per gap multiplied by 4 turns, or \$0.0693 f<sup>2</sup> for a four layer IGU.
- Price for 22% Argon and 66% Krypton gas fills at 0.50 inch gaps would be \$0.28 f<sup>2</sup> per gap multiplied by 2 turns, or \$1.68 f<sup>2</sup> for a four layer IGU.
- Price for 95% Krypton gas fill at 0.41 inch gaps gap would be \$0.34 f<sup>2</sup> per gap multiplied by 2 turns , or \$2.08 f<sup>2</sup> for a four layer IGU.

# **$U_{IP}$ & $R_{IP}$ Factors for COG IGUs for 4 Layer Air & Gas Filled Gaps**

- For a high performance 4 layer window using Starphire, 2-HM88-180 with Low-E 2,4,6, the associated U & R factors for COG IGUs are as follows for NFRC 100-2010 (@ 0 °F):
  - 100% Air @ 0.625 inch gaps = U-0.098 (R-10.2)
  - 5% Air & 95% Argon @ 0.57 inch gaps = U-0.082 (R-12.19)
  - 12% Air, 22% Argon & 66% Krypton @ 0.50 inch gaps = U-0.077 (R-13)
  - 5% Air & 95% Krypton @ 0.41 inch gaps = U-0.071 (R-14.1)

# **$U_{IP}$ & $R_{IP}$ Factors for COG IGUs for 4 Layer Air & Gas Filled Gaps**

- For a high performance 4 layer window using Starphire, 2-HM88-180 with Low-E 2,4,6, the associated U & R factors for COG IGUs are as follows for NFRC 100-2010 (@ -35.4 °F):
  - 100% Air @ 0.625 inch gaps = U-0.107 (R-9.34)
  - 5% Air & 95% Argon @ 0.57 inch gaps = U-0.089 (R-11.23)
  - 12% Air, 22% Argon & 66% Krypton @ 0.50 inch gaps = U-0.086 (R-11.63)
  - 5% Air & 95% Krypton @ 0.41 inch gaps = U-0.079 (R-12.66)

# **$U_{IP}$ & $R_{IP}$ Factors for COG IGUs for 6 Layer Air & Gas Filled Gaps**

- For a high performance 6 layer window using Starphire, 2-HM88-180 with Low-E 2,4,6,8,10 the associated U & R factors for COG IGUs are as follows for NFRC 100-2010 (@ 0°F):
  - 100% Air @ 0.625 inch gaps = U-0.062 (R-16.13)
  - 5% Air & 95% Argon @ 0.68 inch gaps = U-0.048 (R-20.83)
  - 12% Air, 22% Argon & 66% Krypton @ 0.50 inch gaps = U-0.046 (R-21.74)
  - 5% Air & 95% Krypton @ 0.41 inch gaps = U-0.044 (R-22.73)

# **$U_{IP}$ & $R_{IP}$ Factors for COG IGUs for 6 Layer Air & Gas Filled Gaps**

- For a high performance 6 layer window using Starphire, 2-HM88-180 with Low-E 2,4,6,8,10 the associated U & R factors for COG IGUs are as follows for NFRC 100-2010 (@ -35.4°F):
  - 100% Air @ 0.625 inch gaps = U-0.063 (R-16.67)
  - 5% Air & 95% Argon @ 0.68 inch gaps = U-0.052 (R-19.23)
  - 12% Air, 22% Argon & 66% Krypton @ 0.50 inch gaps = U-0.049 (R-20.41)
  - 5% Air & 95% Krypton @ 0.41 inch gaps = U-0.046 (R-21.73)

# Actual Field Results

- Though with good Quality Control, 20-41% increases in thermal resistance can be consistently achieved, actual field results are currently representative of only about a 15-10% increase in thermal resistance.
- Thus, enhancing Quality Control could result in consistently increasing thermal resistance of high performance windows by 20-41% and decrease gas leakage to 0.33% annually.

# Noble Gas Economics cont.

- The demand for Xenon in the semi-conductor markets has created a global shortage for Xenon and an increase in inventory for Krypton.
- Xenon and Krypton are produced simultaneously at the rate of 8:92, e.g. there are 92 units of Krypton produced for every 8 units of Xenon produced at high capacity oxygen ASUs.
- Hence, Krypton has dropped in price by 50% in the last ten years.
- If this trend continues, Krypton will become more and more economical for use in high performance windows.

# Reducing Gas Leakage

- When properly installed, hot melt butyl and silicone foam super spacers have been observed to virtually eliminate gas leakage from IGUs.
- Annual leakage rates can be reduced to as little as 0.5% annually after weather cycles.
- This would reduce twenty year losses of Argon and Krypton to less than 10% using EdgeTech/Quanex's silicone foam super spacer technology.

# Percent Argon Gas Loss after Weather Cycling

	Average	Best	Std. Deviation
Swiggle Seal	33.66	0.30	46.16
Polysulfide	8.88	0.10	10.36
Hot Melt Butyl	0.77	0.40	0.33
Silicone Dual Seal	5.78	3.70	2.39
Super Spacer	0.93	0.50	0.45

**Argon Retention - NRC Study (Elmahdy/Yusuf)**

Simulates 5 years weather exposure.

All units dual pane with hard-coated Low E Glass

# Silicone Foam Super Spacer



# Super Spacer Technical Data

- **Super Spacer Premium** is a flexible, silicone foam spacer products that provides the maximum in perimeter insulation for sealed glazing units. Desiccant-filled with pre-applied side adhesive, the structural foam spacer significantly simplifies insulating glass (IG) production.
- Featuring a vapour barrier backing, the product must be applied in combination with conventional IG sealants such as hot melt butyl, polyurethane and solvent-free polysulfide.
- Dual seal equivalent sealants may also be used (reference IG sealants Technical Bulletin RD0018)

# **Optimal Air/Gas Mix & Gap Thickness**

- Based on the above conductivity values and costs for argon and krypton, mixtures of these gases would probably provide the best cost benefits for various low-e glass configurations.
- Using LBNL Window software, modeling should be conducted to determine the optimal gap thickness and the cost benefit for each insulated glass configuration.

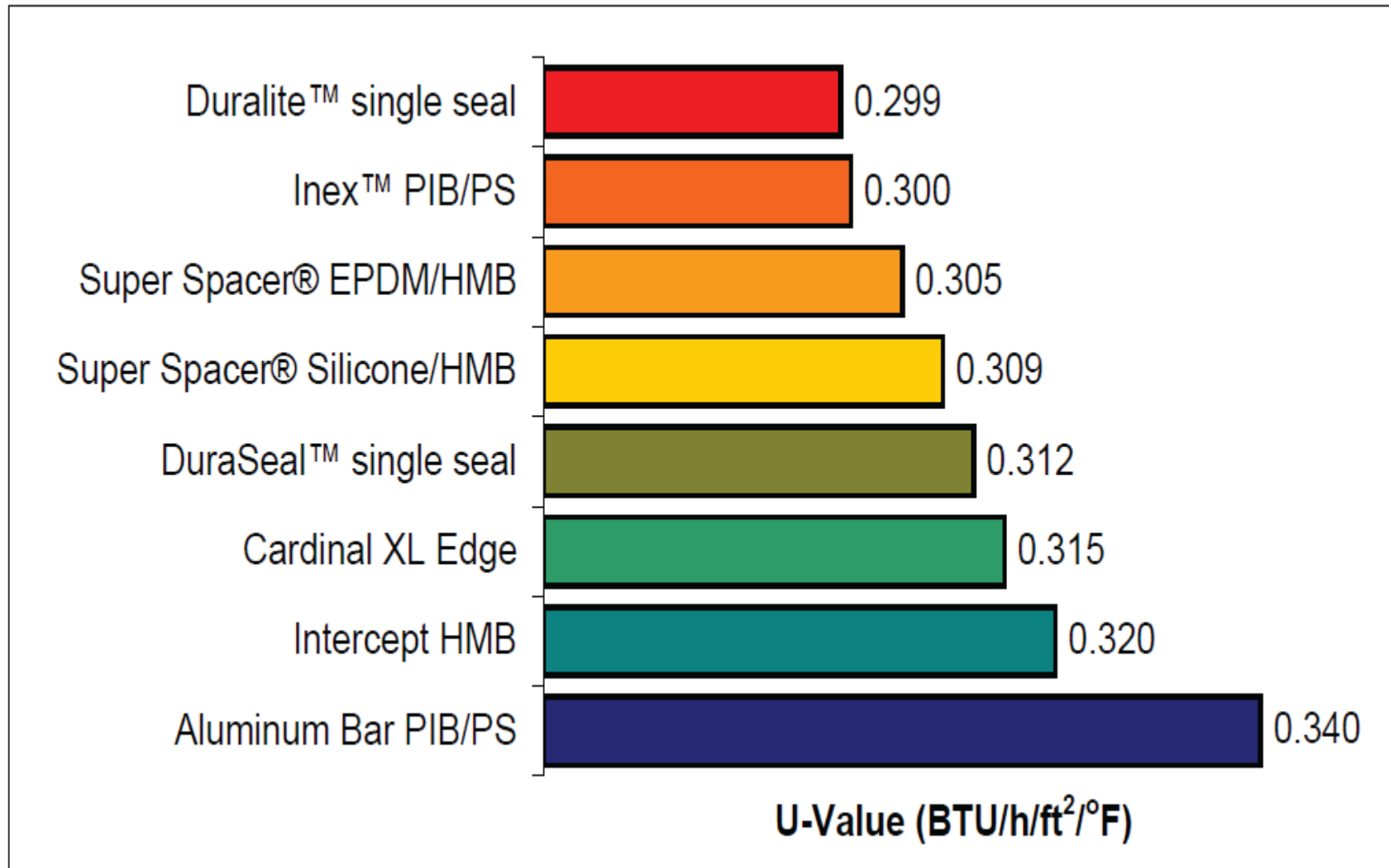
# Thicker IGUs & Frames

- Allowing for thicker gap spaces and use of air or less expensive inert gas can substantially reduce costs while maintaining a relatively high level of performance (U-0.49 to U-0.53) via SCF low-e glazing systems for the following air and air--gas mixes and gap sizes:
  - 100% air (0.625 to 0.75 inch gaps)
  - 5% air and 95% argon (0.65 inch gap)
  - 12% air, 22% argon and 66% krypton (0.5 inch gap)

# State-of-the-Art IGU Spacers

- There are a handful of spacers that are leading the industry when it comes to providing state-of-the-art insulated glass units (IGUs).
- When compared in identical glazing systems and window frames, these spacers provide unsurpassed thermal resistance and over-all performance.
- Though the following whole window comparison was performed according to NFRC 100, 2001, the U-factors reveal how much a well insulated spacer can improve thermal resistance.

Simulations were performed by Enermodal Engineering Limited using Window 5.2 and THERM 5.2 as per NFRC 100, and NFRC 500, 2001.



Computer Modeled Thermal Test Results NFRC-100-2004												
Spacer Comparison												
	Gauge	Total Window U-Value (47.25" x 59")		% Above Aluminum	Frame U-Value		% Above Aluminum	Coldest Glass Temperature		% Above Aluminum	Glass Temperature from sightline	
		W/(m*K)	Btu/h-ft²-F		W/(m*K)	Btu/h-ft²-F		°C	°F		°C	
③	N/A	.461	0.266539	3.6%	.382	0.220863	19.2%	38.8	101.84	29.8%	40.9	
GE )	.008	.471	0.272321	1.5%	.447	0.258445	5.5%	33.7	92.66	12.7%	38.3	
GE )	.008	.468	0.270586	2.1%	.421	0.243412	11.0%	35.3	95.54	18.1%	39.1	
	N/A	.469	0.271165	1.9%	.422	0.24399	10.8%	34.5	94.1	15.4%	38.7	
	N/A	.469	0.271165	1.9%	.422	0.24399	10.8%	34.6	94.28	15.7%	38.8	
1	.008	.473	0.273477	1.0%	.443	0.256132	6.3%	32.8	91.04	9.7%	37.9	

# **EnviroSeal nXt**

## **Polycarbonate Spacer System**

- Duralite™ Warm Edge Spacers in the insulated glass unit improves the total window U-Factor as follows:
  - Duralite™/Inex 0.30 U-Factor (R-3.33 - up 13%)
  - Super Spacer® 0.31 U-Factor (R-3.23 – up 11%)
  - Intercept® 0.32 U-Factor (R-3.13 – up 10.6%)
  - Aluminum Spacer 0.34 U-Factor (R-2.94)
- Simulations were performed using Windows 5.2 and Therm 5.2 as per NFRC 100 and NFRC 100, 2001.

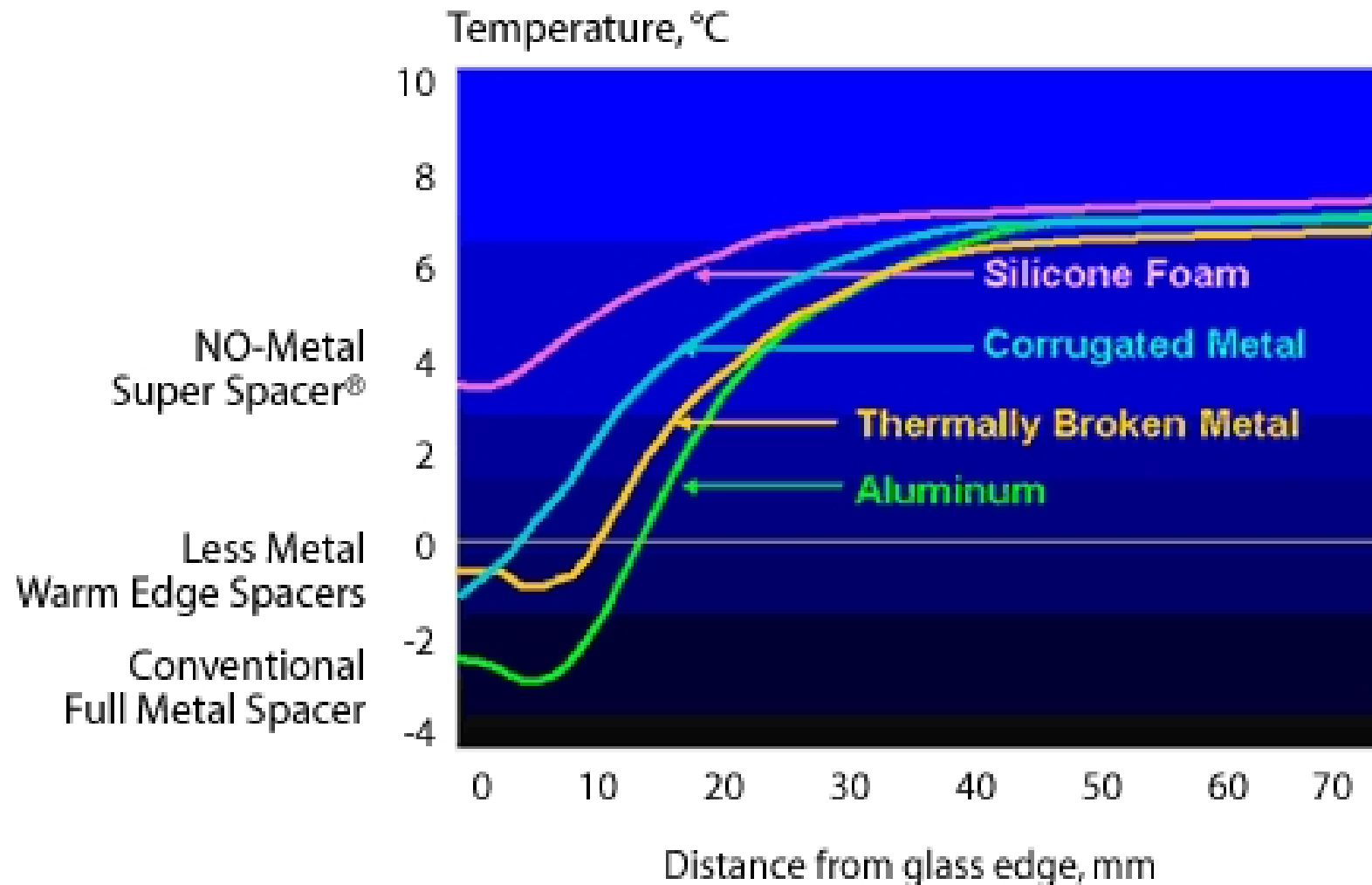
# **Silicone Foam Super Spacer**

- In addition to reducing air leakage, the super spacer technology also enhances thermal resistance for IGUs at the edge of glass, producing a U-value as that measured at the center of glass.
- Eventually, this technology may be used in conjunction with rigid materials required for suspended coated films.

# Performance & Durability

- Super Spacer is currently the best – all-foam, no-metal warm-edge spacer system available which provides a true dual seal:
  - High-performance acrylic adhesive structural seal
  - Moisture vapor butyl seal
- The dual seal helps Super Spacer windows outperform single-seal units in durability tests: up to five times longer.
- Super Spacer is a warm-edge spacer system that uses a high-performance acrylic adhesive for its structural seal, backed by a moisture vapor seal. This is why Super Spacer units last five times longer in durability tests than single-seal units.

# EdgeTech Super Spacer



# NFRC 100-2011 Testing

Spacer System	Condensation Resistance	Edge of Glass Temperature	Effective Thermal Conductivity	Total IGU Factor
Super Spacer Structural Foam / butyl	44.9	43.7°F/6.5°C	0.171 W/(m*K) 0.09887 Btu/h-ft²-F	U <sub>si</sub> -0.277 U <sub>ip</sub> -0.160
Thermoplastic coated corrugated plastic / butyl	38.9	41.1°F/5.06°C	0.207 W/(m*K) 0.1197 Btu/h-ft²-F	U <sub>si</sub> -0.286 U <sub>ip</sub> -0.1654
Stainless Steel U-channel / butyl	38.0	39.2°F/4.00°C	0.252 W/(m*K) 0.1457 Btu/h-ft²-F	U <sub>si</sub> -0.287 U <sub>ip</sub> -0.1659
Stainless box / PIB primary sealant	32.2	34.8°F/1.56°C	0.459 W/(m*K) 0.2654 Btu/h-ft²-F	U <sub>si</sub> -0.293 U <sub>ip</sub> -0.1694
			0.603 W/(m*K)	U <sub>si</sub> -0.304

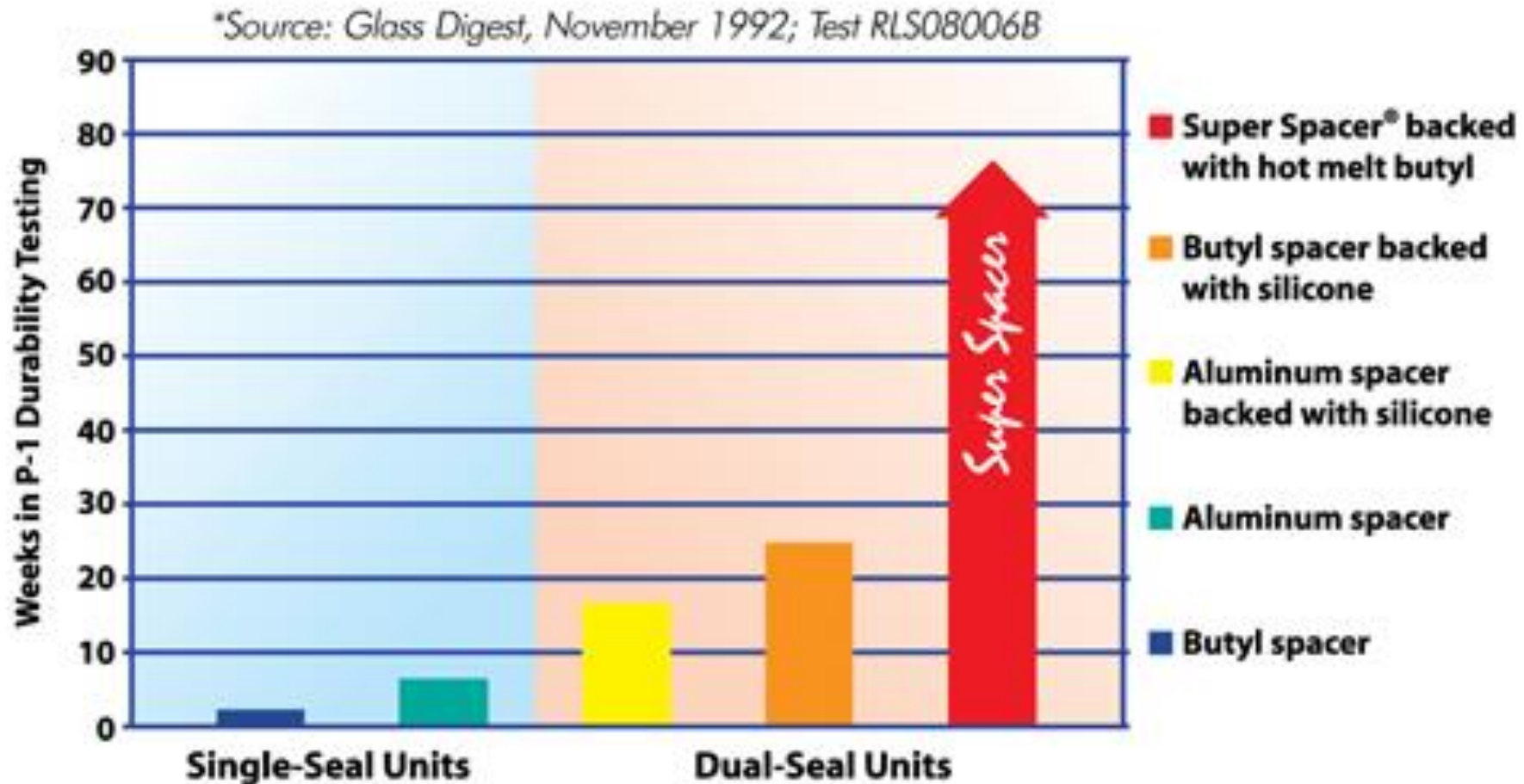
# Super Spacer Durability

- The biggest enemies of window durability are temperature fluctuation and ultraviolet light.
- Super Spacer foam is formulated with a silicone elastomer – unmatched in its thermal stability and ability to withstand UV light.
- The foam's high elasticity allows it to accommodate expansion and contraction.
- Yet its high-memory formula means it returns to its original shape – and a perfect, crack-free seal.

# **Super Spacer Durability cont.**

- Super Spacer windows are the outstanding performers in the industry's toughest durability test.
- In the P1 Chamber, windows are continually exposed to temperatures of 140 degrees F, 95- to 100-percent humidity and high levels of UV radiation.
- One week in the chamber is considered the equivalent to one year in the field. Super Spacer units function perfectly for more than 70 weeks – three times as long as the next-best-performing competing system.

# P-1 Durability Testing



# P-1 Durability Testing cont.

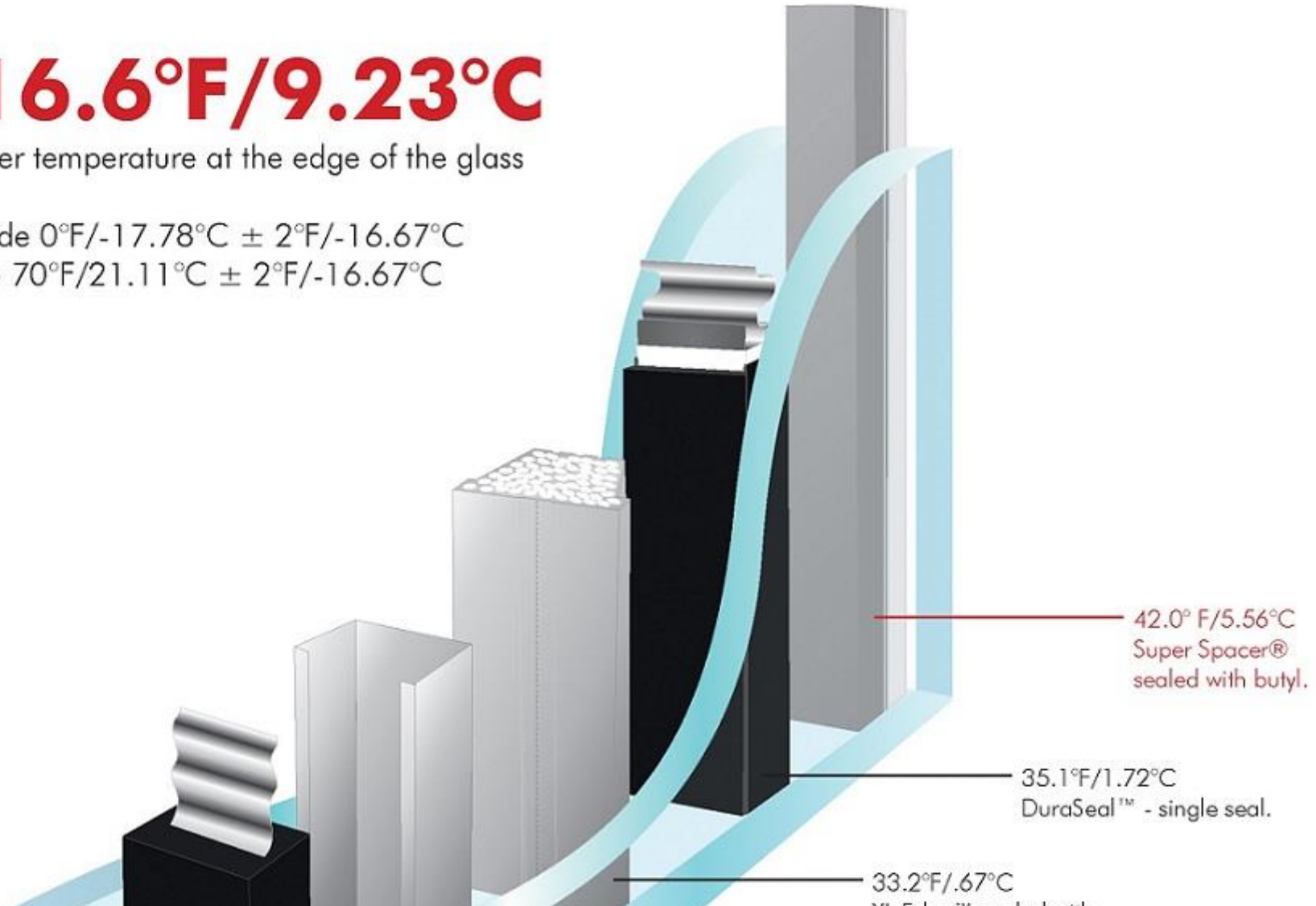
up to

**+16.6°F/9.23°C**

warmer temperature at the edge of the glass

Outside 0°F/-17.78°C ± 2°F/-16.67°C

Inside 70°F/21.11°C ± 2°F/-16.67°C



# Mold Prevention

- The non-conductive Super Spacer protects against a threat that's grown as homes have become more airtight: mold.
- Window condensation is a frequent contributor to molds which have been linked to increased rates of respiratory infections, allergies and asthma.

# Sound Absorption

- Metal is not only a great conductor of heat; it also conducts sound extremely well.
- Closed-cell foam is second only to open-cell foam in its ability to absorb sound.
- This allows the Super Spacer technology not only keep out the elements, but also noise.

# **R-14 to R-16**

## **Insulated Glazing Units**

- Progressive window manufacturers are producing glazing systems that can achieve R-14 to R-16 at the center of glass for picture windows.
- However, relatively narrow window foam-filled fiberglass frames and inadequate installation result in lowering the whole window R-value to less than R-9 for the vast majority high performance windows on the market.
- Currently, most whole window packages are rated at less than R-5. This represents less than 50% of what could be achieved using available glazing technologies and thicker better insulated window frames with state-of-the-art thermal breaks.

# **Improving Glazing & Frame Packages**

- Although window glazing technologies such as improved glass, silicone foam super spacers, and gas filled gaps have substantially improved the thermal resistance and over-all energy efficiency of window packages, window frame technology has not kept pace with high performance IGUs.
- The development of thicker walls for energy efficient structures such as ICF, SIP, and double wood frame exterior walls provide 8-16” of space that are ideal for development and adoption of thicker, more energy efficient window frames.

# Hybrid Frames & VIP Technology

- Though center of glass for IGUs can be increased to under U-0.043 (over R-23) for multiple glazing systems using SCF technology, most window frames and sashes achieve less than R-5.
- Increasing the thermal resistance of window frames is a key strategy for increasing the total thermal resistance of high performance windows.
- Development of porous solids using nanotechnology provide an opportunity to vastly increase the thermal resistance of window frames and installation processes.

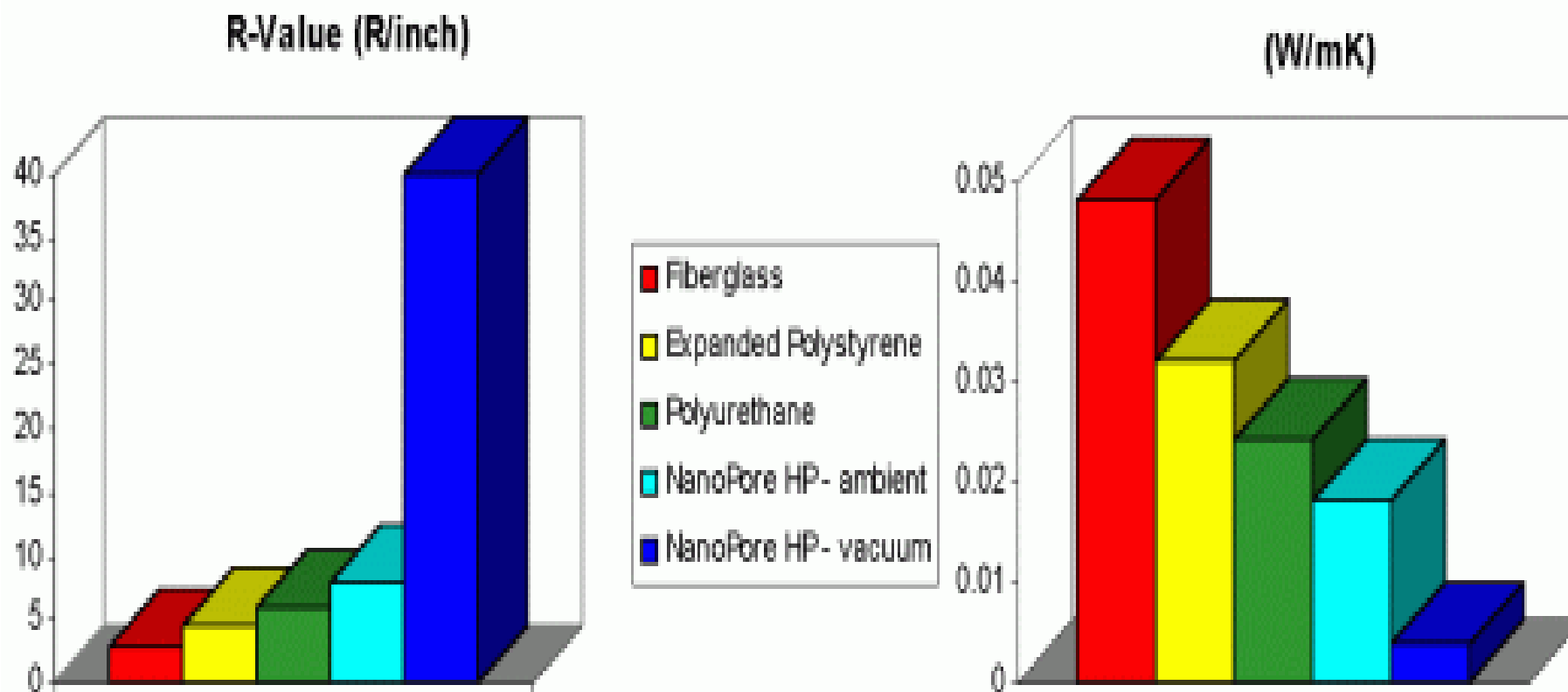
# VIP (R-40/inch) Insulation

- **NanoPore™** thermal insulation is a porous solid that is prepared by one of several processes which yield both low density and small pores.
- Its chemical composition is silica, titania and/or carbon in a 3-D, highly branched network of primary particles (2-20 nm) which aggregate into larger (nm to mm) particles.
- The material has pore sizes ranging from 10-100 nm. It is this nano-scale porosity that gives NanoPore™ its excellent thermal performance.

# Vacuum Insulation Panel

- Because of its unique pore structure, NanoPore™ Thermal Insulation can provide thermal performance unequalled by conventional insulation materials.
- In the form of a vacuum insulation panel ([VIP](#)), NanoPore™ Thermal Insulation can have thermal resistance values as high as R40/inch - 7-8x greater than conventional foam insulation materials.
- A comparison of the thermal performance of NanoPore™ Thermal Insulation versus conventional insulation materials is listed below.

# R-40 VIP Insulation



# Glazing Layers/Panes

- One of the shortcomings of glass is its relatively poor insulating qualities.
- As illustrated above, multiple panes of glass with air or gas filled gaps in between improve the insulating value considerably.
- Relative to all other glazing options, clear single glazing allows the highest transfer of solar energy while permitting the highest daylight transmission.

# The Knudsen Effect

- Due to the unique nano-structure of VIP products, its conductivity can actually be lower than air at the same pressure.
- Its superior insulation characteristics are due to the unique shape and small size of its large number of pores.
- Gas molecules within the matrix experience what is known as the Knudsen effect, which virtually eliminates exchange of energy in the gas, effectively eliminating convection and lowering overall thermal conductivity.

# Solid Phase Conduction

- Solid phase conduction is low due to the materials low density and high surface area, and NanoPore™'s proprietary blend of infra-red opacifiers greatly reduce radiant heat transfer.
- NanoPore™ Insulation may be used over a wide temperature range from below cryogenic ( $<-196\text{ }^{\circ}\text{C}$ ) to high temperatures ( $>800\text{ }^{\circ}\text{C}$ ).

# NanoPore™ Thermal Insulation Products

- The standard thermal insulation product is NanoPore™ HP-150.
- It can be used at temperatures up to 300°C.
- For use with higher temperatures NanoPore produces a special high temperature insulation, NanoPore™ HT-170 for use up to 800°C and above in some cases.
- For applications with highly specific performance requirements, custom grades of NanoPore™ Thermal Insulation can be provided to meet a project's special needs.

# Semi-rigid Insulation Boards

- NanoPore™ thermal insulation begins as a proprietary blend of nanoporous powders which are pressed into semi-rigid boards.
- The boards are then cut to size and shrink-wrapped for ease of handling.
- For some applications these boards are used directly, but in most cases they are processed into vacuum insulation panels, either by NanoPore or by the end user.
- End users may purchase these boards as VIP inserts.

# Vacuum Insulation Panel

- To make a VIP, the inserts are encased in a metalized plastic barrier film and then sealed under vacuum.
- Various barrier materials may be employed to provide the desired performance depending upon the temperature, size, and desired lifetime.
- The completed product is a vacuum insulation panel ([VIP](#)).

# Temperature Range

- A standard VIP can operate in a temperature range from below -330°F (<-200°C) to 250°F (120°C), the maximum continuous working temperature of the barrier film.
- For higher temperature applications, custom vacuum enclosures, made from metal or another impermeable skin, may be used to house the core material.

# Thermal Break

- Vacuum insulation panels (VIPs) may be ideal for providing state-of-the-art thermal breaks for hybrid window frames.
- Depending on cost, VIPs could also be used to install high performance windows.
- These approaches could potentially result in producing frames and installing windows without affecting COG U-values, providing unprecedented energy efficiency.

# Uval vs. SHGC & Tvis

- As each additional pane of glass adds to the insulating R-value (Uval) of the assembly, it also reduces the visible light transmission (Tvis) and the solar heat gain coefficient.
- Adding a [low-E coating](#) to a surface, or multiple surfaces, of the triple-pane unit will increase the energy performance. Depending on the type of low-E coating, the SHGC and VT will also be affected.
- Adding [gas fills](#) between the layers of glass will also improve energy performance.

# Double Glazing & Low-e Coatings

- Double glazing reduces heat loss (as reflected by the U-factor) by more than 50% in comparison to single glazing. Although U-factor is reduced significantly, the VT and SHGC for a double-glazed unit with clear glass remain relatively high.
- Adding a [low-E coating](#) to a surface of the double-pane unit will increase the energy performance. Depending on the type of low-E coating, the SHGC and VT will also be affected.
- Adding a [gas fill](#) between the layers of glass will also improve energy performance.

# Multiple Glazing Units

- Additional panes of glass increase the weight and thickness of the unit, which makes mounting and handling more difficult and transportation more expensive.
- There are physical and economic limits to the number of glass panes that can be added to a window assembly.
- However, multiple-pane units are not limited to glass assemblies.

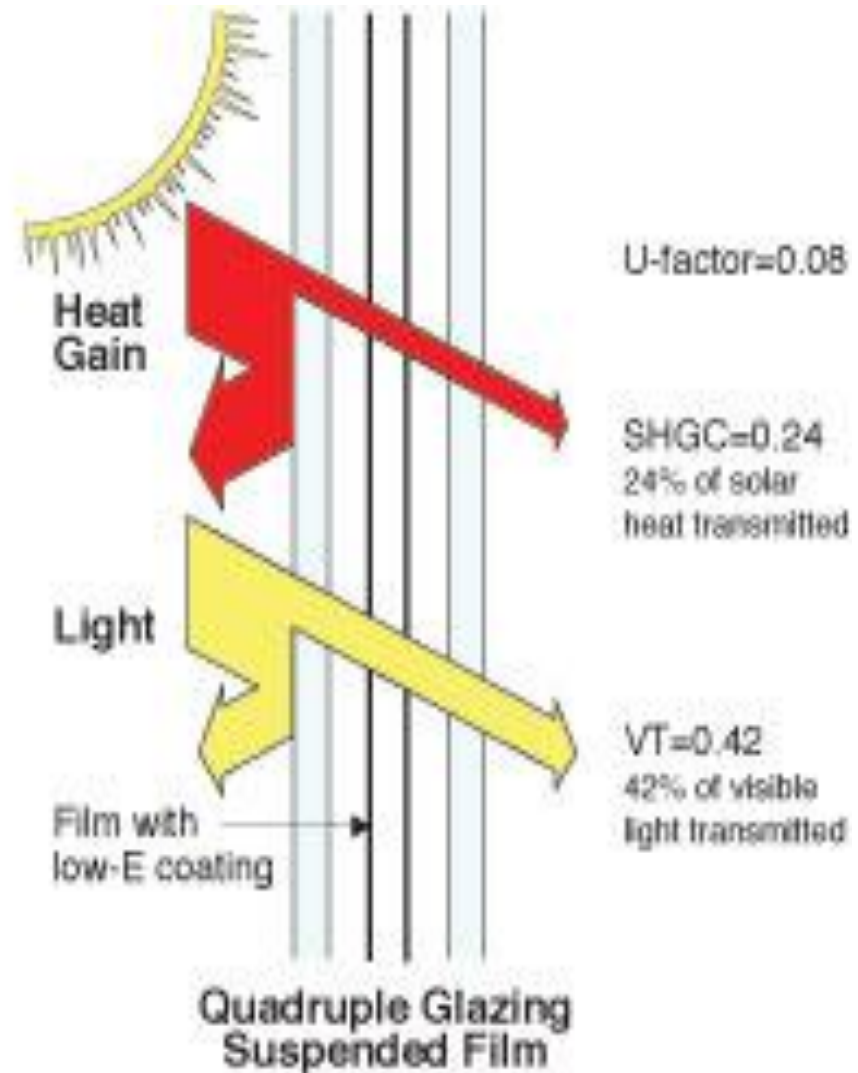
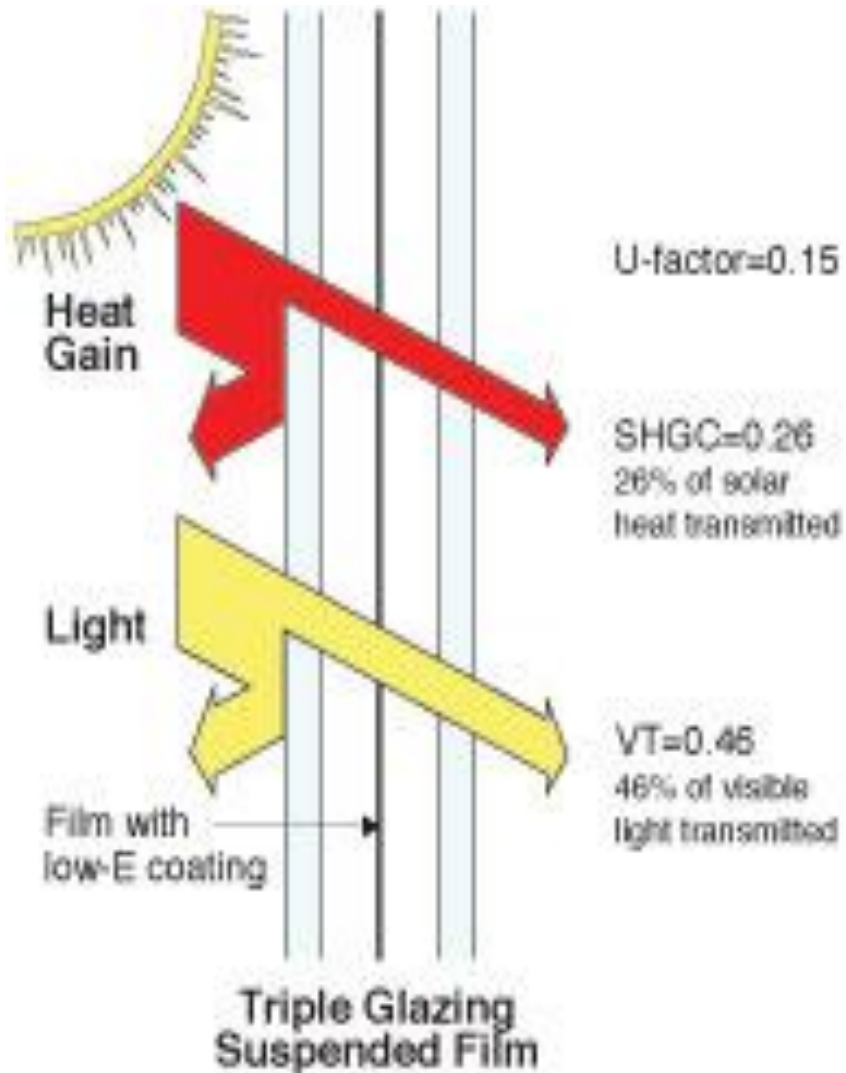
# Heat Mirror/Suspended Film Technology

- The middle layers of glass in an IGU can be substituted with an inner plastic suspended film. The light weight of plastic film is advantageous, and because it is very thin, does not increase the unit thickness.
- Windows using plastic films decrease the U-factor of the unit assembly by dividing the inner air space into multiple chambers. When protected by glass panes from scratching, wear, weathering, and visual distortions caused by wind, the limited strength and durability of the plastic film is overcome.

# Heat Mirror/Suspended Film Technology cont.

- The plastic films are specially treated to resist UV degradation and are heat shrunk so they remain taut and flat. Like glass, a low-E coating can be bonded to the plastic film to lower the assembly U-factor.
- The plastic film can also be treated with spectrally selective coatings to reduce solar gain in hot climates without significant loss of visible transmittance. The low-E coatings can be applied to the glass or plastic.

# Multiple Pane Hybrid IGUs



# Hybrid Glass & SCF IGUs

- The combination of multiple glass panes and plastic films with low-E coatings and gas filled gaps achieves very low center-of-glass U-factors—as low as 0.05 using xenon gas.
- Relatively expensive heat mirror technology is commonly used for squeezing more glazing panes into narrow ( $7/8''$  to  $1\ 3/8''$  thick) insulated glass units (IGUs) using krypton gas for conventional window manufacturing of frames that are about  $3.25''$  thick.

# **Heat Mirror/Suspended Coated Films vs. Glass Pane Technology**

- Optimal thermal resistance is obtained through separation of glass panes with 0.65” gaps filled with air and relatively inexpensive argon gas.
- Unlike glass, heat mirror technology usually requires metal spacers to stretch the plastic film tight and hold it in place.
- This can decrease thermal resistance in comparison with glass and more efficient warm edge spacers.

# **Maximum Insulating Efficiency of a Standard IGU**

- The maximum insulating efficiency of a standard IGU is largely determined by the thickness of the space containing the gas.
- Too little space between the panes of glass results in heat loss by diffusion between the panes (heat from one pane travelling through the air or fill gas to the other pane) while if too large a gap is used, convection currents are not damped out by the air or gas viscosity and transfer heat between the panes.

# Optimum Gap (Air/Gas Space)

- Typically, most sealed units using air and argon achieve maximum insulating values using an air/ gas space of 16–19 mm (0.63–0.75 inches) when measured at the center of the IGU.
- When combined with the thickness of the glass panes being used, this can result in an overall thickness of a double pane IGU of 22–25 mm (0.87–0.98 inches) for 3 mm (0.12 inches) glass to 28–31 mm (1.1–1.2 inches) for 6.35 mm (0.250 inches) plate glass.

# Triple Pane IGUs

- Allowing for 0.75 inches (19 mm) between panes would result in a triple pane IGU that is 44-50 mm (1.74-1.96 inches) for 3 mm (0.12 inches) glass to 56–62 mm (2.2–2.4 inches) for 6.35 mm (0.250 inches) plate glass.
- Including the window frame, this could increase the total thickness of the IGU and window frame to well over 3.5 inches, requiring thicker walls than is provided by 2x4 wood construction, but possibly okay for 2x6 walls.

# IGU Thickness

- IGU thickness is a compromise between maximizing insulating value and the ability of the framing system used to carry the unit.
- Some residential and most commercial glazing systems can accommodate the ideal thickness of a double paned unit.
- Thicker walls that provide higher levels of insulation can accommodate thicker higher performing window frames for super windows.

# Triple Glazing Systems

- Issues arise with the use of triple glazing to further reduce heat loss in an IGU.
- The combination of thickness and weight results in units that are too unwieldy for most residential or commercial glazing systems, particularly if these panes are contained in moving frames or sashes, e.g., operable windows.

# Vacuum Insulated Glass

- This trade-off does not apply to Vacuum Insulated Glass (VIG), or evacuated glazing, as heat loss due to [convection](#) is eliminated, leaving radiation losses and [conduction](#) through the edge seal.
- These VIG units have most of the air removed from the space between the panes, leaving a nearly-complete [vacuum](#) which has roughly the same conductance/conductivity as argon.

# Limitations of VIG Technology

- VIG units which are currently on the market are hermetically sealed along their perimeter with solder glass, that is, a glass frit having a reduced melting point.
- Such a glass seal is rigid, and will experience increasing stress with increasing temperature differential across the unit.
- This stress may prevent vacuum glazing from being used when the temperature differential is too great. One manufacturer provides a recommendation of 35 °C.

# **Limitations of VIG Technology cont.**

- Even though the vacuum needed in a VIG window is “softer” than that used in extremely efficient Thermos bottles ( $10^{-4}$  torr instead of  $10^{-6}$  torr in the parlance of vacuum physics, or one-hundredth as strong a vacuum), the edge seal is still extremely important.
- If the vacuum seal is lost, that R-10 to R-12 window would probably end up not much better than R-2.

# **Limitations of VIG Technology cont.**

- In most cases, the edge seal is a “hermetic, glass-to-glass bond using a non-organic, lead-free solder glass frit material.”
- In other words, it’s not a glue or traditional sealant that’s commonly used in sealed insulated-glass units.
- The “frit” is a “modified version of a proven material that has been around for several decades” and is used in both flat-screen and older-style, picture-tube televisions.

# **Limitations of VIG Technology cont.**

- One drawback to a VIG window is that the tiny pillars that keep the panes of glass separated slightly affect the optical clarity of the windows.
- When viewed at a low angle, these tiny beads are visible to some people. Guardian has found in focus groups that about 50% of people were able to see them. It's unclear how much of an issue this will be in windows used for views; it shouldn't make any difference in windows above the vision plane or in skylights.

# **Developing Thicker IGUs & Window Frames**

- Though VICs provide opportunities to reduce IGU thickness, the technology is still in early stages of development.
- As conventional insulated glazing units continue to increase in thermal performance, particularly for triple pane IGUs, this will lead to developing thicker IGUs and thicker window frames for high performance windows.

# Low Heat Capacity of Monatomic Gases

- Gas-filled gaps replace air in the space with a lower thermal conductivity gas.
- Gas convective heat transfer is a function of viscosity and specific heat.
- Monatomic gases such as argon, krypton and xenon can be used since (at normal temperatures) they do not carry heat in rotational modes, resulting in a lower heat capacity than poly-atomic gases.

# **Strategic Development of Low-Cost High Performance IGUs**

- Argon has a thermal conductivity 67% that of air, and Krypton has about half the conductivity of Argon. However, Krypton and Xenon are much more expensive.
- These gases are used because they are non-toxic, clear, odorless, chemically inert, and commercially available because of their widespread application in industry.

# Optimum Gap Thickness

- In general, the more effective a fill gas is at its optimum thickness, the thinner the optimum thickness is. For example, the optimum thickness for krypton is lower than for argon, and lower for argon than for air.
- However, since it is difficult to determine whether the gas in an IGU has become mixed with air at time of manufacture (or becomes mixed with air once installed), many designers prefer to use thicker gaps than would be optimum for the fill gas if it were pure.

# **Argon and Air**

## **Ideal for Larger Gaps**

- Argon is commonly used in insulated glazing as it is the most affordable.
- Krypton, which is considerably more expensive, is not generally used except to produce thin double glazing units or relatively thin, or extremely high performance triple glazed units.
- Similar performance as that provided by Krypton can be economically achieved simply by developing thicker gaps in triple pane IGUs that use air and argon gas.

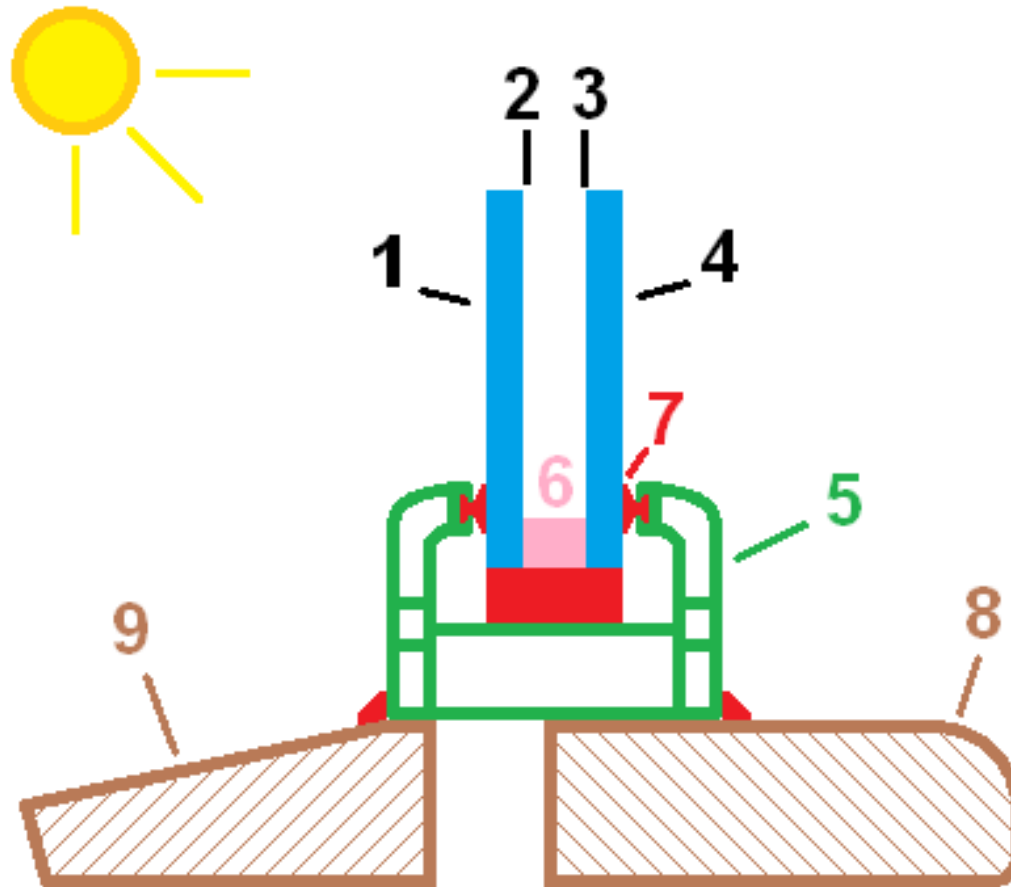
# Development of Wider Frames

- As IECC 2012 and other organizations promote continuous super-insulation (resulting in wider exterior walls and more energy efficient windows), there is a strategic opportunity for developing thicker IGUs and window frames using a combination of materials such as:
  - Foam-filled fiberglass exteriors with 86% of the structural strength of aluminum but with less weight and more thermal resistance
  - Foam-filled wood interiors that provide a thermal break and warm, appealing aesthetics

# Increasing Thermal Resistance of Insulated Glass Units

- The effectiveness of insulated glass can be expressed as an [R-value](#). The higher the R-value, the greater is its resistance to heat transfer.
- A standard IGU consisting of clear uncoated panes of glass (or lites) with air in the cavity between the lites typically has an R-value of  $0.35 \text{ K}\cdot\text{m}^2/\text{W}$ .

# Anatomy of and IGU & Window Frame



# Anatomy of an IGU & Window Frame cont.

- The above is a [sectioned](#) diagram of a fixed Insulated Glazed Unit (IGU).
- Surface #1 is facing outside, Surface #2 is the inside surface of the exterior pane, Surface #3 is the outside surface of the interior pane, and Surface #4 is the inside surface of interior pane.
- The window [frame](#) is labeled #5, a [spacer](#) is indicated as #6, seals are shown in red (#7), the internal [reveal](#) is on the right hand side (#8) and the exterior [windowsill](#) on the left (#9)

# Argon Gas & Low-e Glass

- Using US [customary units](#), a rule of thumb in standard IGU construction is that each change in the component of the IGU results in an increase of 1 R-value to the efficiency of the unit.
- Adding Argon gas increases the efficiency to about R-3.
- Using low emissivity glass on surface #2 will add another R-value.

# High Performance Windows

- Properly designed triple glazed IGUs with low emissivity coatings on surfaces #2 and #4 and filled with argon gas in the cavities result in IGUs with R-values as high as R-5.
- Certain vacuum insulated glass units (VIG) or multi-chambered IGUs using coated plastic films result in R-values as high as R-12.5.
- High performance window manufacturers such as Alpen have achieved R-14 at the center of glass using krypton and 1 3/8 inch IGUs.

# Thicker IGUs Provide for Multi-Glazing Systems

- Additional layers of glazing provide the opportunity for improved insulation.
- While the standard double glazing is most widely used, triple glazing is not uncommon, and quadruple glazing is produced for very cold environments such as Alaska.
- Even quintuple glazing (four cavities, five panes) is available - with mid-pane insulation factors equivalent to walls.

# **Ultra-Efficient IGUs & Installed Windows**

- Using low-e glass configurations, 0.65 inch 10% air and 90% argon-filled gaps, it is possible to achieve over R-13.33 at center of glass for five pane IGUs, and up to R-11.4 for four pane IGUs.
- With efficient warm edge spacers, foam-filled fiberglass exteriors, and wood (perhaps foam-filled) interiors, and state-of-the-art foam installations, it may be possible to economically provide R-9 (U-0.11) to R-12.5 (U-0.08) picture windows with low to high solar heat gain (SHG) and 4 inch or larger sized frames.

# Heat Mirror Niche

- Heat mirrors are also referred to as suspended coated films (SCF).
- In the absence of thicker IGUs and stronger window frames, thin heat mirror films provide an alternative to thicker glass glazing for conventional 2x4 exterior wall construction.
- In addition to being thin, the primary advantage of heat mirror films is the reduction in weight and a subsequent reduction in structural strength required for window frames.

# **Disadvantages of Heat Mirror Film Technology**

- Many IGU and window manufacturers don't offer Heat Mirror/Suspended Film because historically, though it less expensive to produce, it has been touted as an advanced glazing technology and so it more expensive to purchase than a triple pane IG even though it has a shorter life expectancy.
- Another disadvantage of heat mirror technology is the use of metal spacers which is less thermally resistant than other materials.

# **Cost Benefit Ratio of HM Technology**

- Energy performance for a 1 3/8", triple pane IG, filled with Argon gas is similar for that of a 1" double pane IG with argon and a Heat Mirror film.
- Thermal resistance can be improved with Quad Glass configurations (two heat mirror films) but the U value will only increase by 0.04 and costs can almost double while sacrificing visual light transmission and SHGC.

# General Glazing Characteristics

- Both heat mirror films and state-of-the-art glass provide the following physical characteristics and benefits:
  - Superior insulating performance (reduces energy costs and enhances comfort)
  - Superior solar shading (reduces expensive cooling costs)
  - UV protection (helps reduce fading)
  - Sound attenuation (reduces outside noise)

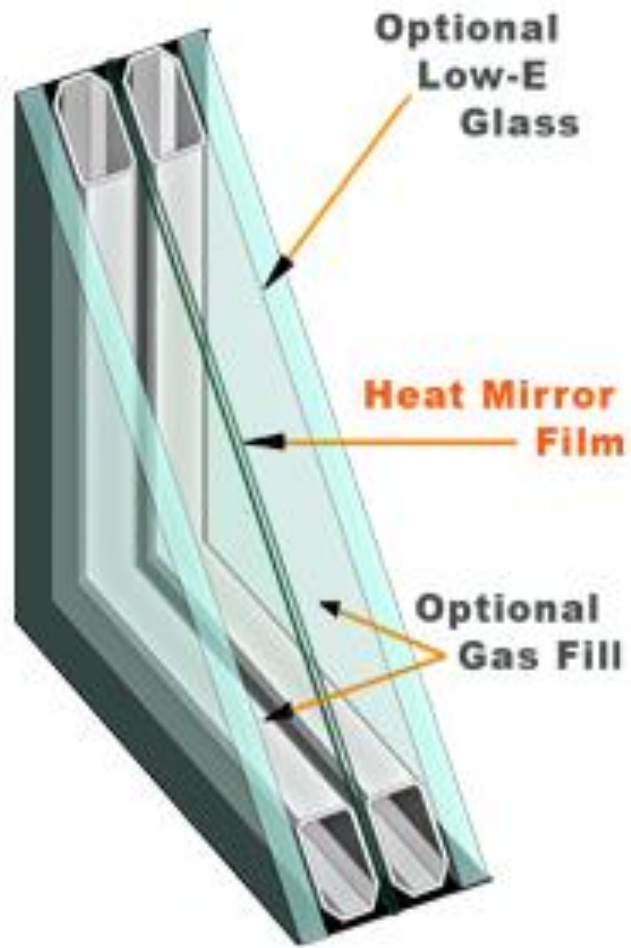
# Heat Mirror/Suspended Coated Film

- Heat Mirror film technology utilizes nanoscale coatings of metal which reflects heat back to its source, hence the name: Heat Mirror.
- Coated Heat Mirror films are often used in conjunction with low-e glass, taking advantage of the benefits of both film-based coatings and glass based technologies.

# Inert Gas Filled Gaps

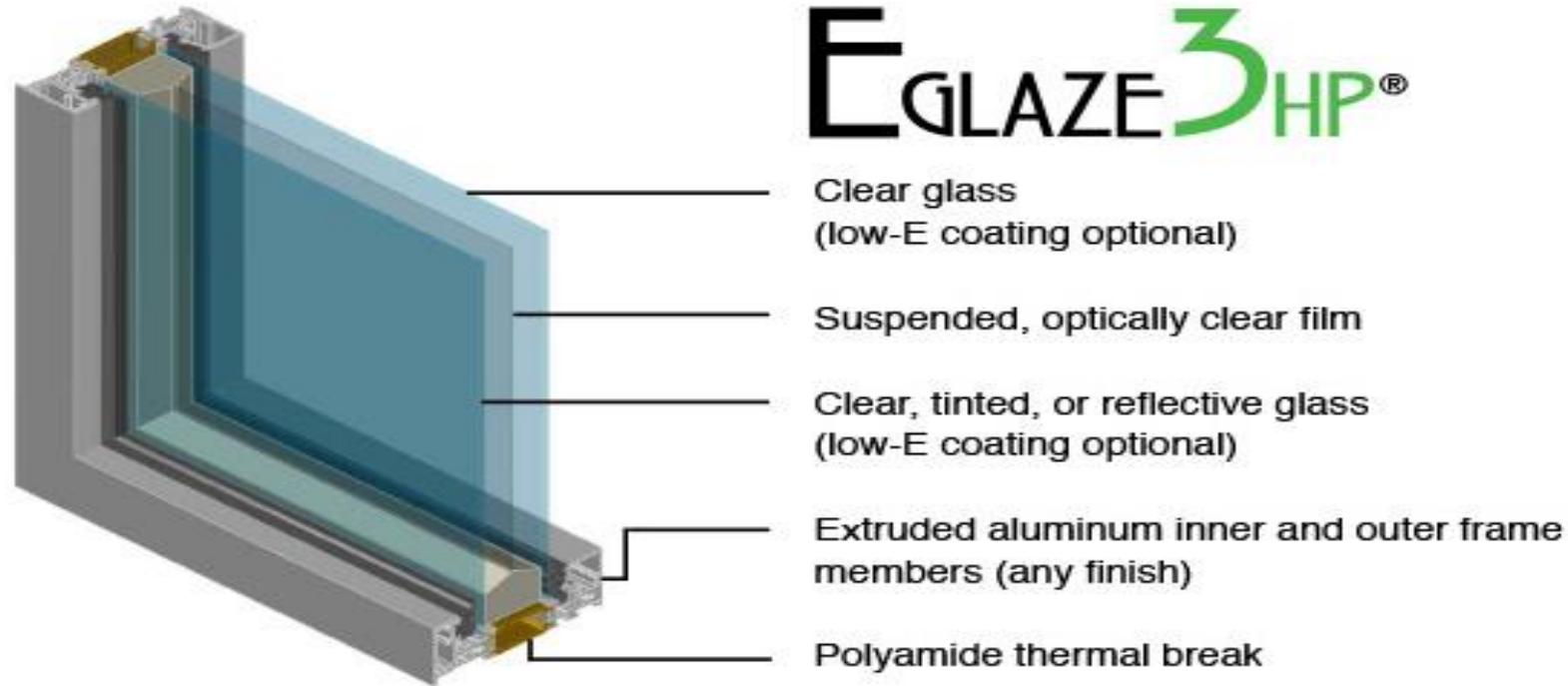
- Inert gases, such as argon or krypton, are added to create Heat Mirror insulating glass units with industry leading performance.
- Outstanding winter insulation and superior solar control provide year-round savings and enhanced comfort.
- In addition, Heat Mirror's UV protection helps protect furnishings from fading, while Heat Mirror's noise reduction maintains a quiet internal environment.

# Single HM Film, Dual Cavity



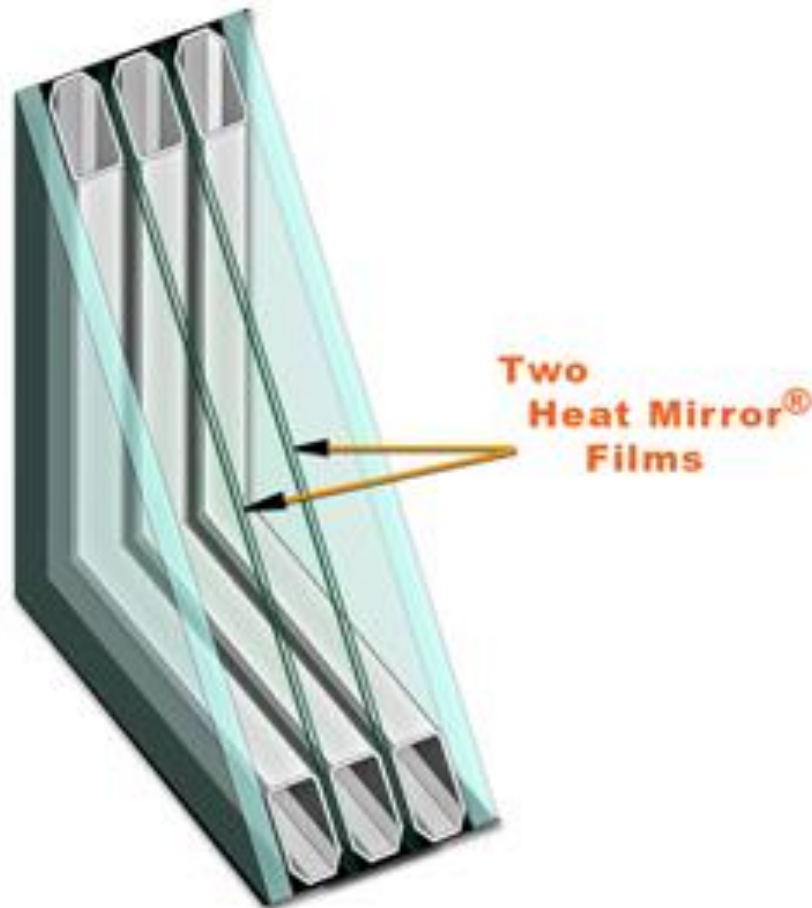
With an optional Krypton gas filling, single-film/dual-cavity Heat Mirror Insulating Glass can achieve a U-value of 0.10 (R-value of 10). All glass or SCF IGUs with Argon or Krypton can achieve U-values of 0.107 (R-9.34).

# Single HM Film-Tri-cavity



Glazing Unit Construction	Outer Lite Glass Type	U-Value (complete window)		Solar Heat Gain Co-efficient (SHGC)	Visible Light Transmission (Tvis)	Shading Co-efficient (SC)
		Btu/hr • ft <sup>2</sup> • F	W/m <sup>2</sup> • K			
<b>Low-E Coat Outer Lite **</b>	Clear	0.207	1.174	0.292	52%	0.34
	Green Tint	0.207	1.174	0.230	45%	0.26
	Grey Tint	0.207	1.174	0.173	26%	0.20
	Blue Tint	0.207	1.174	0.202	33%	0.23

# Dual HM Film-Tri-cavity

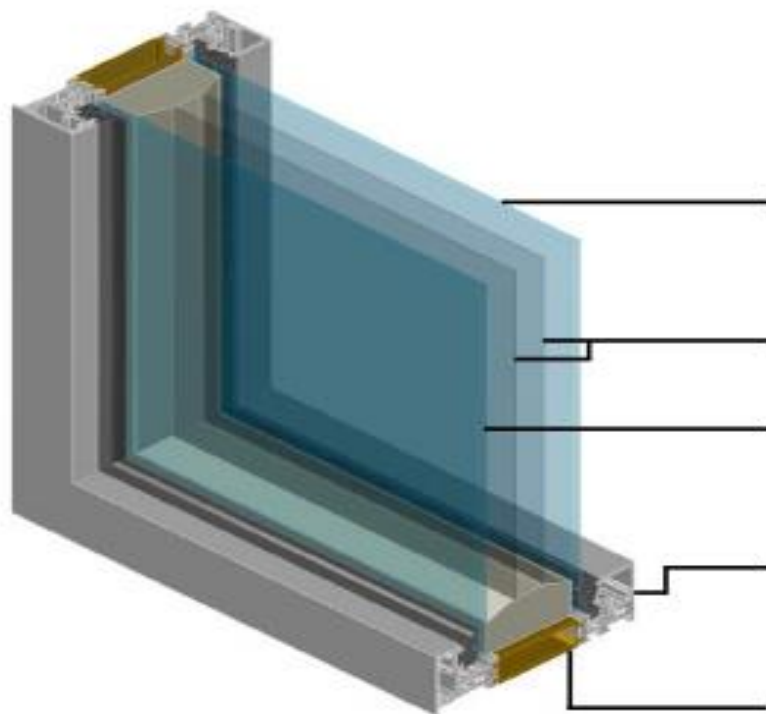


A second Heat Mirror film can be added for even higher insulating performance.

With an optional Krypton gas filling, dual-film/tri-cavity Heat Mirror

Insulating Glass can achieve a U-value of 0.08 (R-value of 12.5). An all glass or SCF tri-cavity IGU using argon or krypton can achieve U-0.089 (R-11.23).

# Dual HM Film-Tri-cavity



**E\_GLAZE 4HP®**

Clear glass  
(low-E coating optional)

Suspended, optically clear film

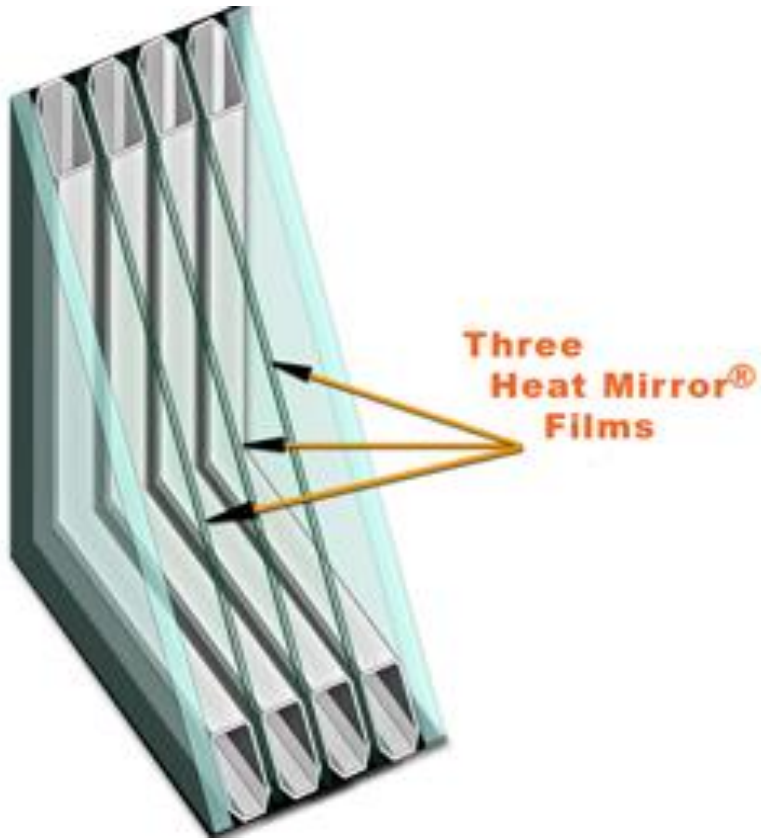
Clear, tinted, or reflective glass  
(low-E coating optional)

Extruded aluminum inner and outer frame  
members (any finish)

Polyamide thermal break

Glazing Unit Construction	Outer Lite Glass Type	U-Value (complete window)		Solar Heat Gain Co-efficient (SHGC)	Visible Light Transmission (Tvis)	Shading Co-efficient (SC)
		Btu/hr • ft² • F	W/m² • K			
<b>Low-E Coat Outer Lite **</b>	Clear	0.144	0.816	0.258	46%	0.30
	Green Tint	0.144	0.816	0.201	39%	0.23
	Grey Tint	0.144	0.816	0.152	22%	0.17
	Blue Tint	0.144	0.816	0.178	29%	0.20

# Tri HM Film-Quad Cavity



Heat Mirror Insulating Glass using three Heat Mirror films suspended inside of an insulating glass unit, creating four air spaces, is one of the most energy-efficient glazing products in the world. With an optional xenon gas filling, tri-film/quad-cavity Heat Mirror Insulating Glass can achieve an industry-leading U-value of 0.05 (R-value of 20). In comparison, LBNL Window 7 modeling reveals that thicker and heavier all glass or SCF IGUs with quad cavities can achieve U-0.053 (R-18.87) using krypton.

# **Cost Comparison**

## **Suspended Coated Films vs. Glass**

- All glass triple pane IGUs run about the same cost as a triple pane IGU using suspended films sandwiched by glass panes.
- Quad glazing using two suspended films sandwiched with glass panes is slightly more expensive than a triple glazed window.
- Five glazing systems that provide quad-cavities for achieving U-0.05 (R-20) require manual labor which substantially increases costs for high performance suspended film windows.

# Achieving Net-Zero Energy

- Quad-Cavity R-20 products can be achieved by suspending either three lightweight heat mirror films or glass within an IGU, creating four independent and super-insulating airspaces (cavities).
- When configured with Krypton gas fill and low-emissivity (“low-e”) coatings on the second and tenth glass surfaces, the Quad-Cavity product provides a 0.05 center of glass U-factor and 0.09 full-unit U-factor for a typical light commercial fixed fiberglass frame for a picture window.
- Different combinations of film and low-e glass can be used to optimize performance for either maximum solar heating in cold climates or maximum solar shading in warm climates.

# Optimal Gap Width

- Glazing systems in the US are commonly designed with a 1/2 " (12.7 mm) gap. The optimal gap width depends on many factors, such as gas fill (air, argon, krypton), the use of Low-e coatings, the environmental conditions (temperature difference across the window), and the calculation standard used.
- NFRC standard conditions are -18 C (-0.4 F) outside, and 21 C (69.8 F) inside. The calculation standard used in the US is based on the ISO 15099 standard.
- European standard conditions are 0 C (32 F) outside, and 20 C (68 F) inside. The calculation standard is based on the EN 673 standard.

# **LBNL Research**

- A number of common glazing configurations both with and without Low-e coatings, and with a variety of gas fills were evaluated using both the North American NFRC standard and the European EN 673 standard.
- All results were calculated by Christian Kohler and Robert Hart using WINDOW 6.3 from LBNL and are extracted from an extensive Excel spreadsheet data base. All IGU's (Insulated Glazing Units) have a standard height of 1 meter.

# Optimal IGU Gap Thickness

Glazing System	Coatings/ Gas fill	Standard	Optimal gap width	
			(mm)	(inches)
Double	Clear (no coating) / Air	US (NFRC)	13	0.512
		EN (EN 673)	16.6	0.6535
	Low-E coating / Argon	US (NFRC)	11.5	0.453
		EN (EN 673)	15	0.59
Triple	Low-E coating / Argon	US (NFRC)	14	0.5512
		EN (EN 673)	> 18	0.7087

# **Optimal Gap Thickness for Four and Five Pane IGUs**

- Contrary to EN 673, US NFRC gap standards appear to be most efficient in terms of providing optimal gap thicknesses.
- Using LBNL Window modeling, results reveal that continually increasing the gap thicknesses for various gases can actually have a negative effect on thermal resistance and associated U-values.

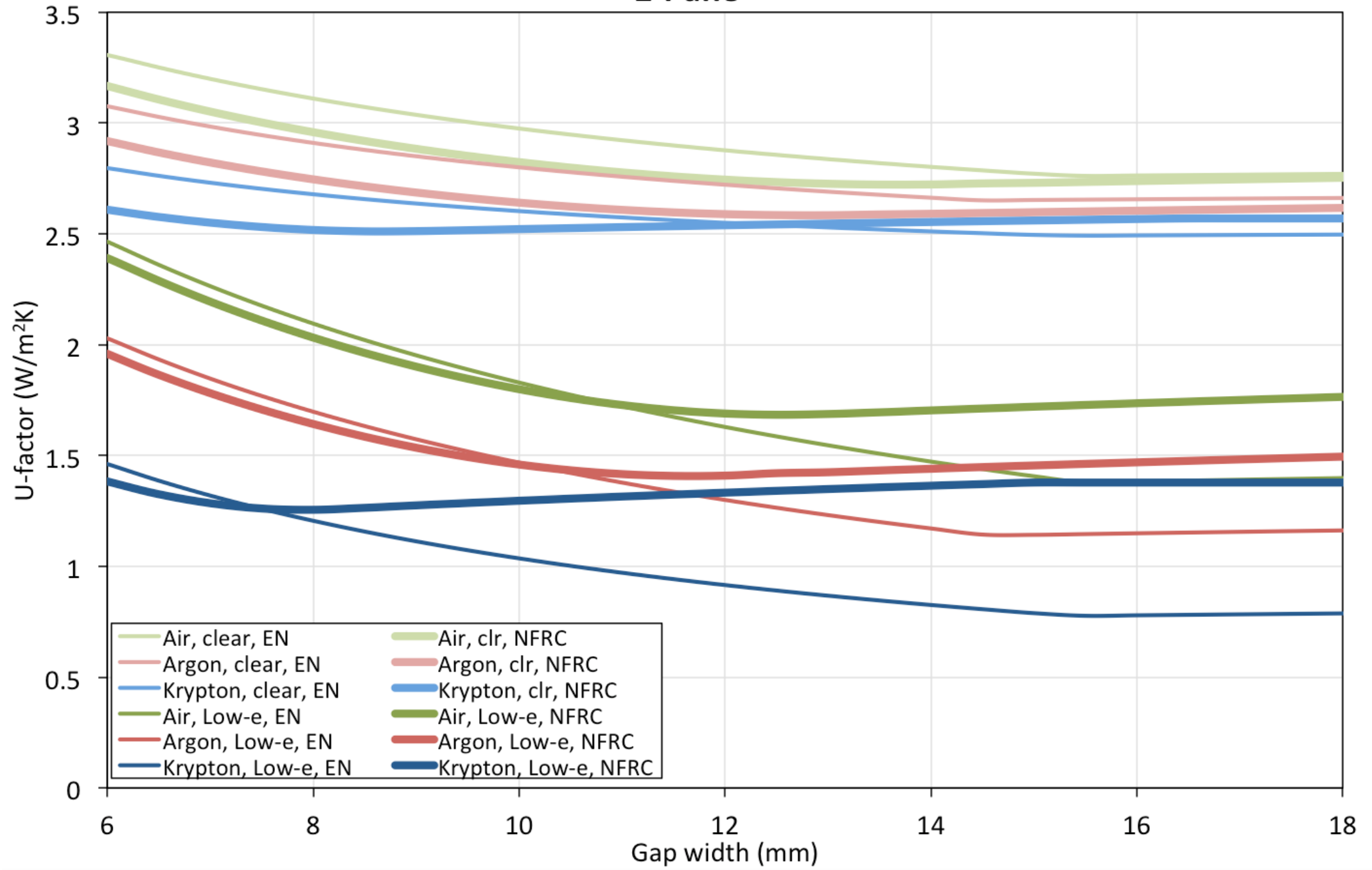
# US NFRC vs. EN 673

- The above table below reveals that the optimal gap thickness for glazing systems designed for European temperature conditions, and using the European EN-673 standard, always have thicker/wider optimal gap.
- Many more data points are available in the graphs and the Excel spreadsheet courtesy of LBNL testing for various other configurations for double and triple pane IGUs.
- [http://windows.lbl.gov/adv\\_Sys/hi\\_R\\_insert/GapWidths.html](http://windows.lbl.gov/adv_Sys/hi_R_insert/GapWidths.html)

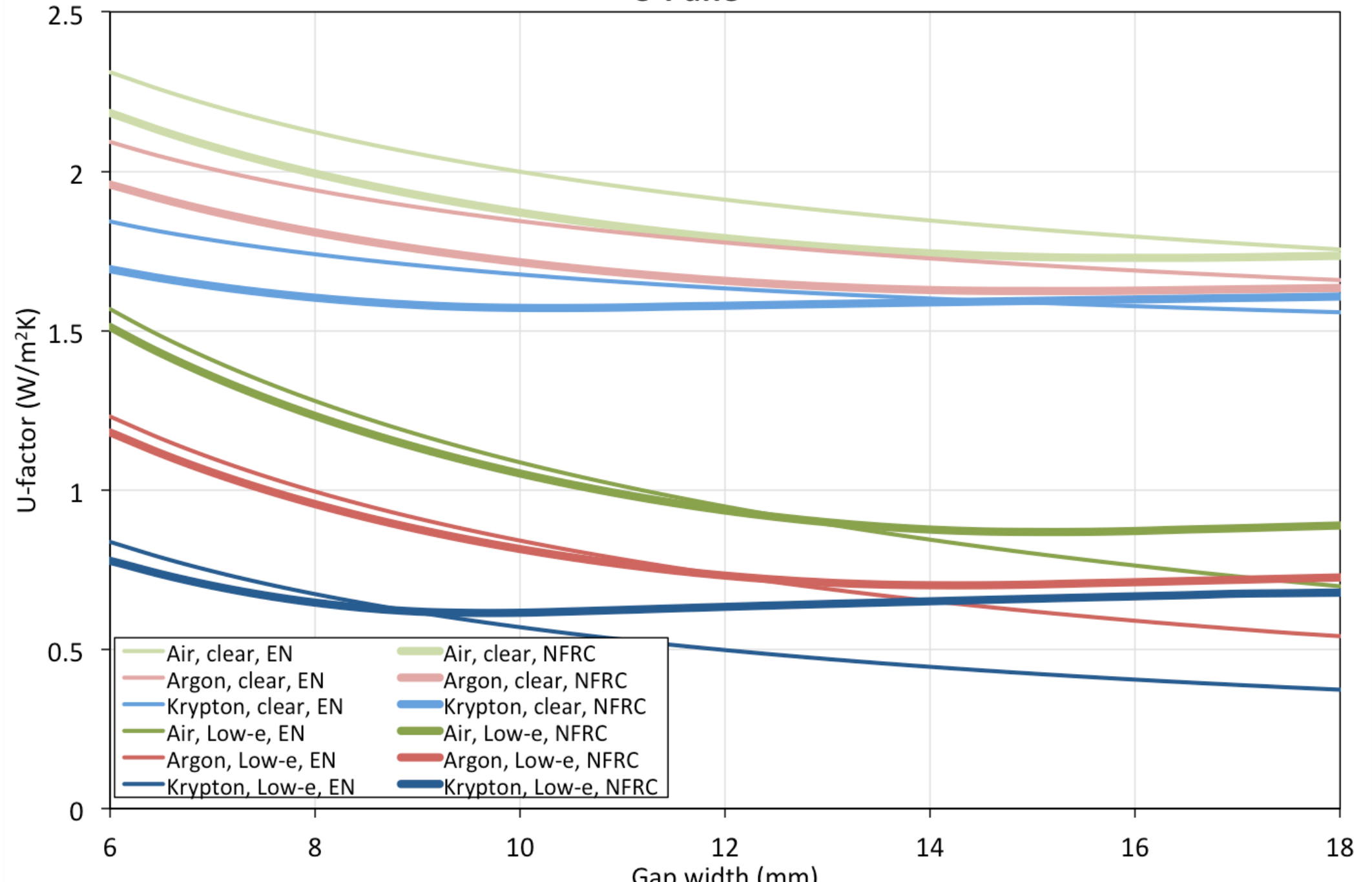
# Ultra-High Performance vs. Economics

- For very high performance systems such as a triple glazed IGU with Krypton gas fill and Low-e coatings, the optimal gap width is  $>18$  mm ( $>0.71$  inches).
- Creating a triple with each gap  $>18$  mm would create a very wide glazing unit, with issues related to pressure build-up in the unit.
- At the same time the amount of Krypton gas needed to fill two  $>18$  mm gaps would be considerably expensive.

## 2-Pane



### 3-Pane



# Calculating Gap Thicknesses for Four & Five Pane IGUs

- Similar data as that compiled for double and triple pane windows by the LBNL may eventually need to be compiled.
- In the meantime, the gap thicknesses determined through modeling by the LBNL for double and triple pane windows should provide relatively accurate gap thicknesses for use in 4 and 5 pane IGU configurations.

## **All Glass 5L 180 LoE IGUs with 100% Air (NFRC-100)**

- Using optimal gap thickness of 0.650 inches for 100% air provides U-0.058 (R-17.24) and SHGC of 0.422, visible transmittance of 0.535, excellent UV protection via Tdw-ISO 0.333, and an IGU thickness of 3.201 inches.
- Envision Building Innovations, Inc., currently provides 5-6 layer HM88 systems with air gaps of 0.625 with U-0.059 (R-16.94) for self-breathing/equilibrium systems.

## **All Glass 5L 180 LoE IGUs with 5% Air & 95% Argon (NFRC-100)**

- Using optimal gap thickness of 0.57 inches for 5% air & 95% Argon provides U-0.058 (R-17.24) and SHGC of 0.427, visible transmittance of 0.535, excellent UV protection via Tdw-ISO 0.325, and an IGU thickness of 2.881 inches.
- Using an optimal gap thickness of 0.41 inches for 5% air and 95% Krypton provides U-0.050 (R-20) and SHGC 0.427, visible transmittance of 0.535, excellent UV protection via Tdw-ISO 0.333, and an IGU thickness of 2.241 inches.

## **5L HM88-180 LoE IGUs with 5% Air & 95% Krypton (NFRC-100)**

- Using gap thickness of 0.75 inches for 100% air provides U-0.072 (R-13.89) and SHGC of 0.381, visible transmittance of 0.533, excellent UV protection via Tdw-ISO 0.332, and an IGU thickness of 3.256 inches.
- Using an optimal gap thickness of 0.41 inches for 5% air and 95% Krypton provides U-0.055 (R-18.18) and SHGC 0.383, visible transmittance of 0.514, excellent UV protection via Tdw-ISO 0.533, and an IGU thickness of 1.896 inches.

# **Optimal Performance & Low Cost**

- In contrast to using air, argon and krypton, using an optimal gap thickness of 0.26 inches for pure xenon provides U-0.052 (R-19.23), SHGC 0.431, with IGU thickness of 1.746 inches.
- These rudimentary modeling results could substantially be improved by glass scientists and IGU engineers using LBNL data and gap formulas.

# Summary

- Provided similar gaps and inert gases are utilized, all glass IGUs using warm edge spacers can potentially meet or exceed the thermal resistance provided by heat mirror film technologies.
- The use of less expensive Argon vs. Xenon or Krypton inert gases can substantially lower costs.
- However, all glass IGUs would be considerably thicker and heavier, requiring stronger more durable frames than those used with heat mirror films.
- Heavier windows could also increase handling and transportation costs.

# Integrated Window System

- When strategic glazing and passive solar gain are utilized in conjunction with southern orientation of the structure, radiant glass for picture windows, zoning, and reducing HVAC requirements for the perimeter of the structure, unprecedented energy efficiency can be achieved.

# **Addition of Radiant Glass**

- The ability to add an additional pane of glass to an existing window configuration can substantially improve the energy performance of that window.
- This strategy allows for strategic provision of radiant glass for picture windows, particularly for windows on the North, West and East sides of the structure that typically are not used for solar heat gain and which are responsible for the majority of heat loss.

# Picture Windows & Bay Windows

- Due to physical design and function, picture windows are more energy efficient than operational windows.
- Hence, the window scheme for the PHMH will be focused on using picture windows whenever possible instead of operational windows while providing necessary egress.
- Bay windows allow for providing both operational and picture windows for integration with radiant glass.

# Strategic Sizing Windows

- In addition to southern orientation of the structure (for maximizing solar heat gain), windows can be sized according to location on the structure.
- For example, smaller windows can be utilized on the Northern, Western and Eastern sides of the structure to reduce heat loss.

# Reduction of Perimeter HVAC

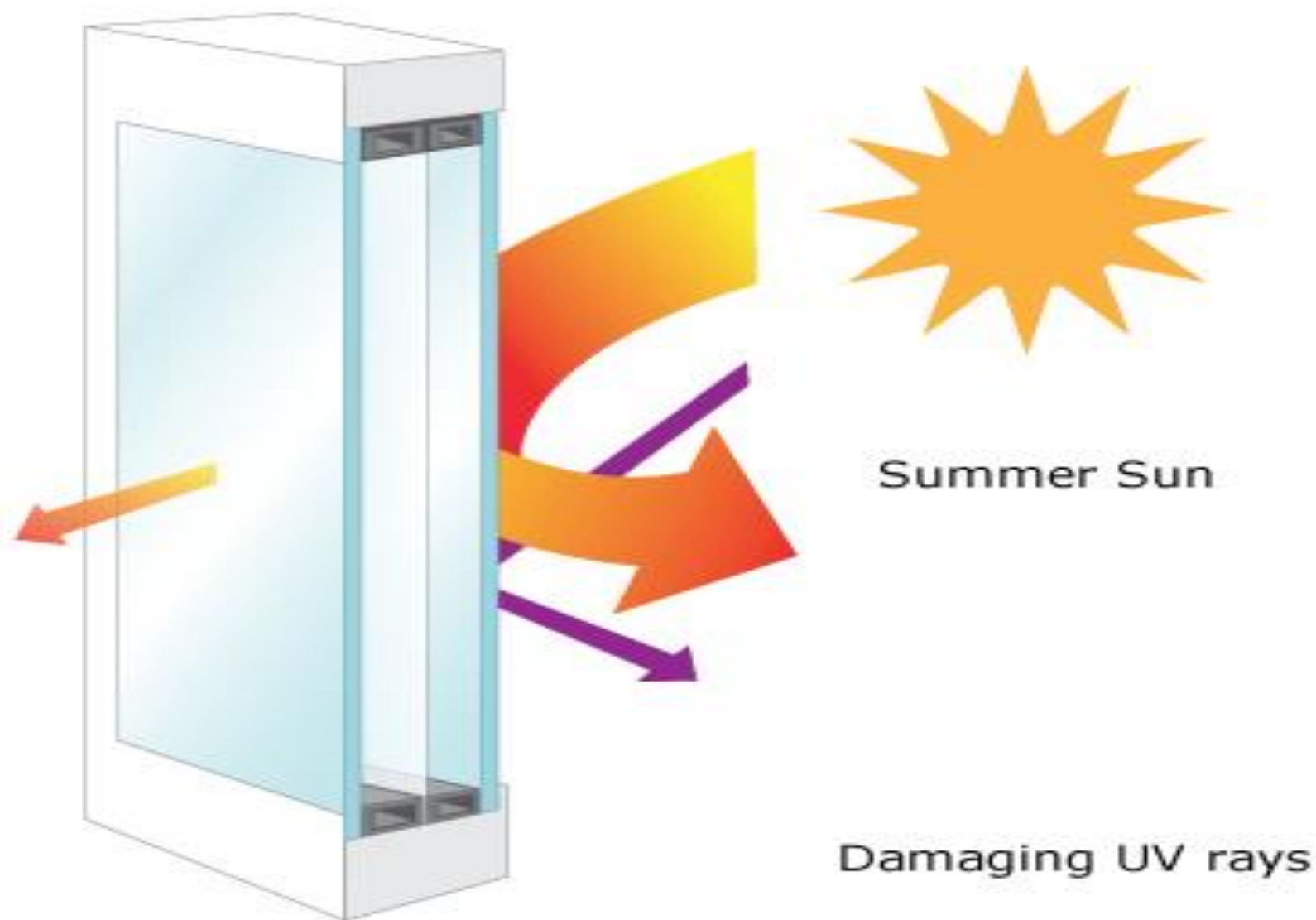
- The addition of radiant glass and associated controllers will allow for strategically designing the HVAC ducting system and temperature zones via thermostats to reduce heating loads by over 20% for the PHMH.
- When integrated with affordable triple glazed windows (two glass panes and one suspended film pane) and fiberglass frames, optimal internal rates of return can be achieved for very energy efficient systems.

# High Efficiency Windows & Doors

- Alpen & Marvin windows and glass doors are leading the US industry in passive house design and architecture by developing state-of-the-art glazing, fiberglass insulated frames, and warm edge spacer technology.
- Triple or quadruple glazing casement and picture windows with radiant glass will be utilized, possibly with retractable shades for southern Idaho's desert climate.
- Whenever possible, emphasis will be on orienting homes on building lots to take full advantage of southern exposure for passive solar heat gain.

# Alpen Windows

## Summer Solar Heat Control



# Alpen Windows

## Winter Passive Heating



# **Five Factors That Affect Full Frame R-value of a Window**

- The type of glazing material (e.g., glass, suspended film, treated glass)
- The number of air chambers created by multiple layers of suspended film or glass panes
- What type of gas, if any, is used to fill the air space(s)
- The thermal resistance of the frame and spacer materials
- The “tightness” of the window – how much air leaks through (infiltration)

# Understanding Full-Frame R-Values for Windows

- R-Value is a measure of thermal resistance used in the building industry.
- A high-R-value window has a greater resistance to heat flow and a higher insulating value than one with a low R-value.
- R-value is the inverse of the U-factor ( $R = 1/U$ ) and is expressed in units of hr-sf-°F/Btu.

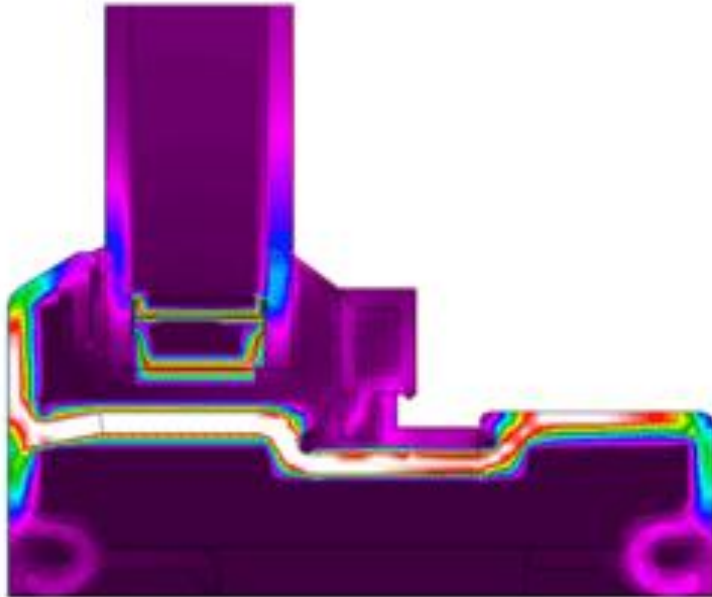
# **Aluminum vs. Fiberglass Frame**

- The thermal image below shows the cross section of a standard dual-pane low-e aluminum framed window and the cross section of Alpen Windows' fiberglass frame with two panes of glass and one layer of suspended film (SCF).

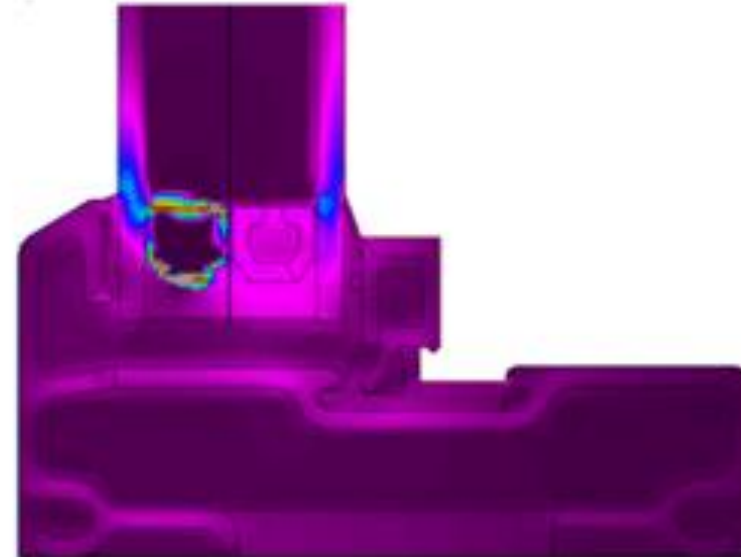
# Modeled via THERM 6.1 Simulation Software Developed by Lawrence Berkeley National Labs

## Models of window cross sections – aluminum vs. fiberglass

Typical Aluminum, Dual Pane Low-E



Fiberglass super-insulated frame, Dual Pane with SCF



# Thermal Image Interpretation

- The colors depicted show the amount of thermal energy (Btu/h-ft<sup>2</sup>) passing through the frame. Purple means virtually no thermal energy is transferring through.
- The more green, red, orange and yellow means the more thermal energy that is passing through with red representing the most energy being transferred.
- The white areas in the image at left indicate the highest level of heat transfer – this is like a highway for heat to leave the home.

# Importance of Framing System

- The thermal image clearly reveals that in well made multi-paned, low-e windows, the main source of thermal energy transfer is through the framing system.
- Knowing the full frame R-value of a window is critical for ensuring a high quality, energy efficient window.

# Triple Pane vs. Suspended Film

- The transition from single pane glass to dual pane (with a single chamber) provided an improvement in window energy performance. In much the same way, the introduction of multiple-chamber glass packages – with two to three insulating chambers and multiple surfaces using lightweight, suspended film layers – allow for significant improvements and advantages over triple-pane windows.
- Triple-pane windows are often viewed as the best performing window on the market. This is a flawed concept; triple-pane windows do not automatically equate into the best thermal performance. Thermal performance of a window is dependent on the entire window system, not just the number of panes.

# Problems with Triple-Pane Windows

- Triple-pane glass units are significantly heavier than Alpen Windows.
- The heavier glass units require stronger framing systems which can increase the overall cost of buildings.
- The extra weight can also impose strict size constraints, and may affect how much glass is used in the design of a building – impacting the overall aesthetics of a structure, as well as comfort, the amount of natural day-lighting in a building, and even energy efficiency performance.
- General functionality of triple-pane windows is also affected by their weight.
- Additional stress is placed on all operable mechanisms of a triple-pane window as well as the window's hardware, wearing them out quicker.

# Disadvantages of Triple Pane Windows

- Increased project costs (more labor, sturdier frames, stronger building design)
- Aesthetic and design limitations due to size constraints imposed on the glass and window units
- Extra weight caused by stress on the entire window frame, potentially creating gaps that will allow air, water and dust infiltration
- Amount of natural light in the overall design may be reduced
- Additional stress on operable portions of the window and window hardware
- Wider glass packages may not fit framing systems or window openings

# Advantages of Suspended Film

- Suspended film (SF) is one of the most significant technologies critical to improving insulation and achieving higher performance across a broad spectrum of glazing characteristics – without any of the design and durability limitations typical of triple-pane glass systems.
- Internally mounted, suspended films work together to complement the benefits of low-e glass. Combining both film and glass-based coatings creates a lightweight, multi-chamber insulating glass unit that reflects heat and harmful UV radiation while maximizing light transmission, and provides superior insulating performance.
- One or more layers of suspended film in between two panes of glass are separated by low conductivity spacer systems to improve the insulating performance at the edge of the glass unit, providing high full-frame R-values. A variety of inert gases can also be used to fill the air spaces to further block heat transfer.

# **Benefits of Suspended Film glazing in AlpenWindows**

- Directional tuning to enhance day-lighting while better controlling morning warmth and afternoon coolness.
- 99.5+% UV protection reduces interior fading and damage and contributes to healthy, more comfortable indoors.
- More architectural freedom to include more glass in the design than triple-pane windows.
- Better condensation control with more insulating chambers than triple-pane windows.

# Triple Pane vs. Suspended Film Comparison Chart

Window	R <sub>pi</sub> -Value	Avg. winter glass temp (F)	SHGC	Weight per ft.	UV blockage	Tuned solar control system
Alpen Windows	Up to R-9.1	65	.20-.60	3.4	99%	Yes
Triple Pane w/Low-E	Up to R-5	59	.27	5.1	94%	No

**R-Value:** the higher the number the better the insulating value

**SHGC:** the lower the number the more comfortable the window in the summer heat, while a high number can be used on certain elevations for passive winter-time heating.

**STC Rating:** the higher the number the better the sound abatement.

**Weight per ft:** important to keep weight low to minimize wear on operating hardware.

**Tuned solar control:** the ability to provide windows/gas with different R-value, SHGC, and visible light characteristics to maximize comfort and energy efficiency.

# Selecting Full-Frame Windows for Thermal Efficiency

- Many windows available today can achieve a relatively high center-of-glass insulation performance number.
- However, many are poorly manufactured and are made of a material that is not an effective insulator so building owners will experience draftiness from increased condensation and air leakage.

# AlpenWindows 925 Series

- Up to R-9.1 (U-0.10989) insulation
- 3x Energy Star® rating
- 99.5% UV Protection
- More than three times more efficient than Energy Star standards.
- Quadruple-pane glazing in foam-filled fiberglass frames maximize insulating power to create comfortable, efficient homes in even the most severe cold climates.
- Available in casement, picture windows, and awnings for passive house design.

# Casement Window



**Casement Exterior  
(Sandstone color)**



**Casement Interior  
(with Fir Veneer)**



**Casement Interior  
(showing Screen)**

# HP (High Profile) Picture Window



**(Exterior) Almond color**



**(Exterior) Dark Bronze Color**

# Awning Window



**Exterior - White**



**Interior - Fir Veneer**

# AlpenWindows 925 Series



# Alpen Windows 925 Series Highlights

- Alpen Windows combine an advanced glass package with superior fiberglass framing systems to achieve high insulation performance across the full-frame — not just measured at the center of glass.
- “Tuned” to a home’s unique location and solar exposure: Their tuning expertise and glazing options will ensure the right amount of heat to warm or cool a home for thermal efficiency, maximum comfort, and reduced energy usage.
- Their 925 Series glass packages provide a remarkable inside glass surface temperature of 65°F or more on a cold winter day based on NFRC 100-2010 environmental conditions (0°F outside / 70°F inside / 15 mph wind).

# **AlpenWindows 925 Series Highlights cont.**

- Custom made to match a home's distinctive architecture: Alpen Windows are available in multiple sizes, styles, shapes and colors and with optional stainable wood veneers. Alpen Windows are custom made to meet the homeowner's exact specifications and style at no additional cost.
- Traditional classic wood window aesthetic: Alpen Windows offer the beauty and look of classic wood windows. Alpen Windows fiberglass windows offers custom stainable interior wood veneers and classic lines and grid profiles that match the feel of wood windows but without the hassle, weight and maintenance.

# **AlpenWindows 925 Series Highlights cont.**

- High strength, low conductivity fiberglass frame: Fiberglass is considered the “greenest” material for window frames. Fiberglass offers durability, better thermal performance, and lower embodied energy than vinyl, aluminum, and wood framing materials.
- Clean, contemporary hardware: Alpen Windows hardware offers a unique, clean, contemporary design that does not obstruct views and reduces the tendency of the window to “walk” in buffeting wind conditions. The hardware finish is engineered to resist a wide range of corrosive materials.

# **AlpenWindows 925 Series Highlights cont.**

- Multi-seal weatherstripping design: Alpen Windows conforms to the rain screen principle with high quality air and water tight seals.
- Fiberglass insect screen: The screens are easily removable, non-glare, fiberglass. They will not rust, corrode, stain or impede visibility.

# **AlpenWindows 925 Series Highlights cont.**

- UV protection: Alpen Windows are engineered to block up to 99.5% of harmful UV rays. Their advanced glazing systems reduce fading and interior damage and contribute to a healthy indoor environment – all without obstructing natural lighting and visibility.
- Lifetime warranty: All Alpen Windows are covered by a limited lifetime warranty.
- Easy, safe cleaning: designed to tilt-in, lift-in or pivot-in, Alpen Windows allow for easily cleaning windows from the inside of your home safely and easily.

# **AlpenWindows 725 Series Sliding Windows & Glass Doors**

- Up to R-7.1 insulation exceeds Energy Star® standards
- 99.5% UV protection
- Reduced condensation
- Available in Casement, Picture Windows, and Awnings



# **Advantages of AlpenWindow Technology**

- The cutting-edge fiberglass framing systems of Alpen HPP offer superior performance to conventional fenestration materials in a number of ways: durability, stability and efficiency, making it the optimum material for super-insulating windows and preserving overall performance for the life of a window.
- Extreme corrosion resistance: fiberglass is the only framing material that particularly resists environmental damage caused by corrosive salt air or high temperatures.

# **Advantages of AlpenWindow Technology cont.**

- Superior insulator even in extreme environments: dimensional stability even in extreme thermal cycling (heat, cold humidity), Alpen Windows fiberglass frames offer the aesthetic of classic wood clad windows but with better insulation.
- High condensation resistance: the insulating nature of fiberglass prevents condensation and helps keep humidity within a proper range, this limits the growth of molds and mildew and helps keep your home's interior air quality healthy.

# Advantages of AlpenWindow Technology cont.

- Superior strength to weight ratios: Alpen Window's fiberglass series are ideal for large window openings – they are 86% of the yield strength of aluminum and are pound-for-pound, stronger than aluminum.
- Practically maintenance free: the inherent strength and nature to distribute impact loads even in sub-zero temperatures, fiberglass frames will not suffer the pockmarked surface damage that is common to wood and aluminum windows, and because fiberglass takes paint easily with excellent adhesion, you can change the color of your windows any time you like.

# **Advantages of AlpenWindow Technology cont.**

- Very low coefficient of thermal expansion and contraction: stresses on seals, caulks and joints are minimized, contributing to higher efficiency windows and tight seals that are resistant to air leakage and water penetration.
- High glass to frame ratio: the strength of our fiberglass frames means more of a viewing area because of the higher glass to frame ratio, compared to wood windows.

# AlpenWindows 925 Series

- Up to R-9.1 insulation
- 3x Energy Star® rating
- 99.5% UV Protection
- More than three times more efficient than Energy Star standards.
- Quadruple-pane glazing in foam-filled fiberglass frames maximize insulating power to create comfortable, efficient homes in even the most severe cold climates.
- Available in casement, picture windows, and awnings for passive house design.

# Casement Window



**Casement Exterior  
(Sandstone color)**



**Casement Interior  
(with Fir Veneer)**



**Casement Interior  
(showing Screen)**

# HP (High Profile) Picture Window



**(Exterior) Almond color**



**(Exterior) Dark Bronze Color**

# Awning Window

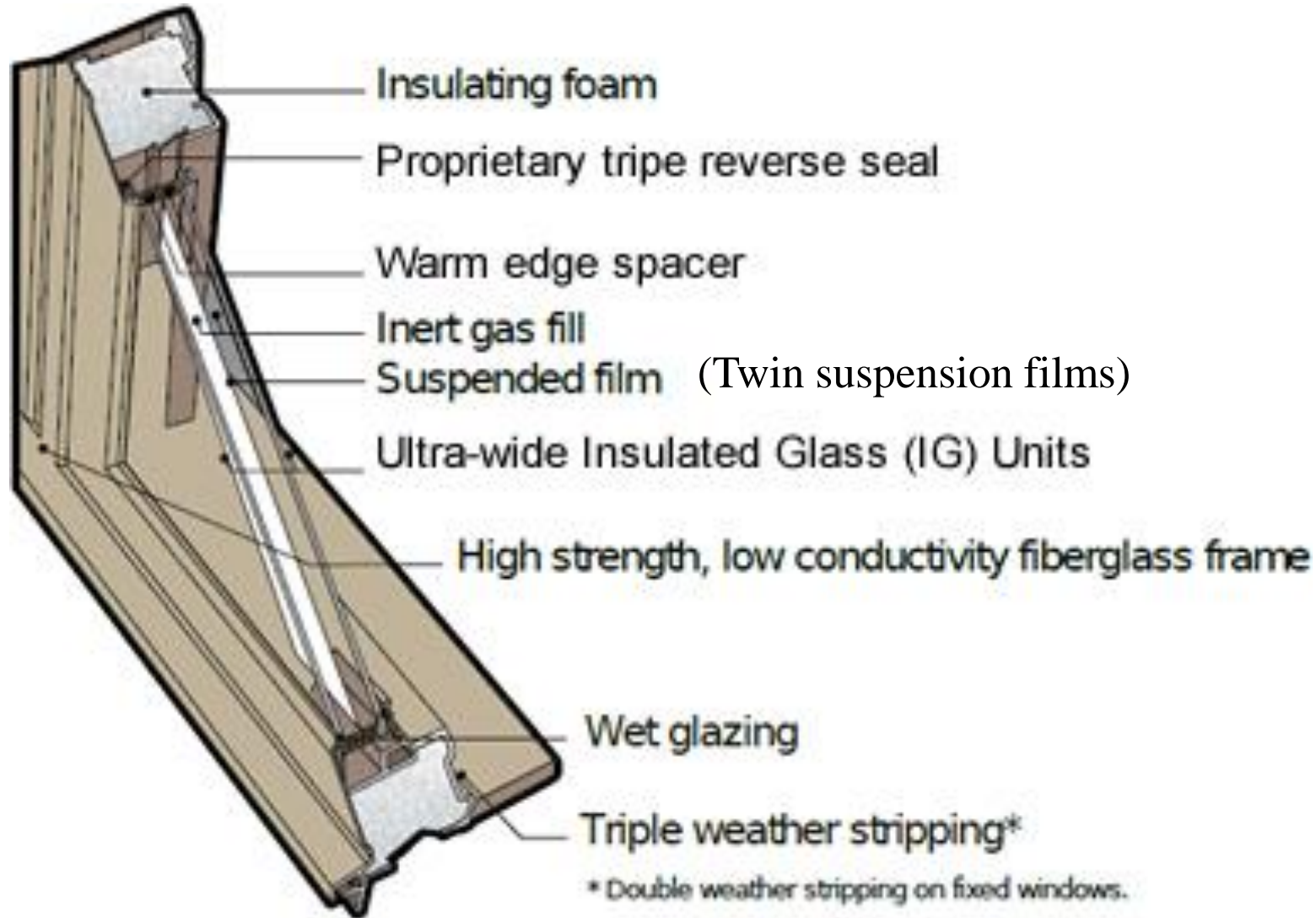


**Exterior - White**



**Interior - Fir Veneer**

# AlpenWindows 925 Series



# Alpen Windows 925 Series Highlights

- Alpen Windows combine an advanced glass package with superior fiberglass framing systems to achieve high insulation performance across the full-frame — not just measured at the center of glass.
- “Tuned” to a home’s unique location and solar exposure: Their tuning expertise and glazing options will ensure the right amount of heat to warm or cool a home for thermal efficiency, maximum comfort, and reduced energy usage.
- Their 925 Series glass packages provide a remarkable inside glass surface temperature of 65°F or more on a cold winter day based on NFRC 100-2010 environmental conditions (0°F outside / 70°F inside / 15 mph wind).

# **Alpen Windows 925**

## **Series Highlights cont.**

- Custom made to match your home's distinctive architecture: Alpen Windows are available in multiple sizes, styles, shapes and colors and with optional stainable wood veneers. Alpen Windows are custom made to meet your home's exact specifications and style at no extra cost.
- Traditional classic wood window aesthetic: Alpen Windows offer the beauty and look of classic wood windows. Alpen Windows fiberglass windows offers custom stainable interior wood veneers and classic lines and grid profiles that match the feel of wood windows but without the hassle, weight and maintenance.

# **Alpen Windows 925**

## **Series Highlights cont.**

- High strength, low conductivity fiberglass frame: Fiberglass is considered the “greenest” material for window frames. Fiberglass offers durability, better thermal performance, and lower embodied energy than vinyl, aluminum, and wood framing materials.
- Clean, contemporary hardware: Alpen Windows hardware offers a unique, clean, contemporary design that does not obstruct views and reduces the tendency of the window to “walk” in buffeting wind conditions. The hardware finish is engineered to resist a wide range of corrosive materials.

# **Alpen Windows 925 Series Highlights cont.**

- Multi-seal weatherstripping design: Alpen Windows conforms to the rain screen principle with high quality air and water tight seals.
- Fiberglass insect screen: The screens are easily removable, non-glare, fiberglass. They will not rust, corrode, stain or impede visibility.

# **Alpen Windows 925 Series Highlights cont.**

- UV protection: Alpen Windows are engineered to block up to 99.5% of harmful UV rays. Their advanced glazing systems reduce fading and interior damage and contribute to a healthy indoor environment – all without obstructing natural lighting and visibility.
- Lifetime warranty: All Alpen Windows are covered by a limited lifetime warranty.
- Easy, safe cleaning: designed to tilt-in, lift-in or pivot-in, Alpen Windows allow for easily cleaning windows from the inside of your home safely and easily.

# **AlpenWindows 725 Series**

## **Sliding Windows & Glass Doors**

- Up to R-7.1 insulation exceeds Energy Star® standards
- 99.5% UV protection
- Reduced condensation
- Available in Casement, Picture Windows, and Awnings



# **Advantages of AlpenWindow Technology**

- The cutting-edge fiberglass framing systems of Alpen HPP offer superior performance to conventional fenestration materials in a number of ways: durability, stability and efficiency, making it the optimum material for super-insulating windows and preserving overall performance for the life of a window.
- Extreme corrosion resistance: fiberglass is the only framing material that particularly resists environmental damage caused by corrosive salt air or high temperatures.

# **Advantages of AlpenWindow Technology cont.**

- Superior insulator even in extreme environments: dimensional stability even in extreme thermal cycling (heat, cold humidity), Alpen Windows fiberglass frames offer the aesthetic of classic wood clad windows but with better insulation.
- High condensation resistance: the insulating nature of fiberglass prevents condensation and helps keep humidity within a proper range, this limits the growth of molds and mildew and helps keep your home's interior air quality healthy.

# **Advantages of AlpenWindow Technology cont.**

- Superior strength to weight ratios: Alpen Window's fiberglass series are ideal for large window openings – they are 86% of the yield strength of aluminum and are pound-for-pound, stronger than aluminum.
- Practically maintenance free: the inherent strength and nature to distribute impact loads even in sub-zero temperatures, fiberglass frames will not suffer the pockmarked surface damage that is common to wood and aluminum windows, and because fiberglass takes paint easily with excellent adhesion, you can change the color of your windows any time you like.

# **Advantages of AlpenWindow Technology cont.**

- Very low coefficient of thermal expansion and contraction: stresses on seals, caulks and joints are minimized, contributing to higher efficiency windows and tight seals that are resistant to air leakage and water penetration.
- High glass to frame ratio: the strength of our fiberglass frames means more of a viewing area because of the higher glass to frame ratio, compared to wood windows.

# Suspended Film Technology

- Similar to Alpen Windows, Marvin has recently released a line of windows with suspended film technology.
- Four layer systems with two suspended films, 90% krypton gas filled spaces, warm edge spacers and with thermal breaks for aluminum clad exteriors and wood interiors should provide up to R-9.1 (U-0.11) thermal performance for energy efficiency.
- Automated shades would further enhance energy efficiency by an estimated U-0.03, decreasing total performance to as low as U-0.08 which is equivalent to R-12.5. The LBNL is currently conducting testing to validate this data.

# Passive Window Shades

- Marvin has designed shades specifically for their passive house certified windows (Ultimate Casement).
- They come with remote control motors that raise and lower blinds at night and mornings as well as during storms (and thus require a total of 5.5” larger window opening beyond the size of the window).
- In addition to blocking solar radiation during warm seasons, these shades provide additional insulation via dead air space during winter and summer months.

# Marvin Passive Window Shade Exterior



# Marvin Passive Window Shade Interior



# Available in Slats or Louvers



# Automated Exterior Shading

- Marvin Windows & Doors automated exterior shading system is fully integrated, fully retractable and fully concealed.
- Now homeowners can enjoy the convenience and energy efficiency benefits of a motorized, fully programmable shading system.
- This proprietary motorized lifting system combines both infrared and radio frequency technology. Unlike current exterior shading systems, Marvin's new patent-pending shading solution uses no bulky add-ons that ruin the line of the windows from outside and block the view from inside.

# Programmable Shades

- Shades can be programmed with timed events to automatically provide exactly the right amount of light 24 hours a day.
- Let in the sun to warm your home naturally during cool weather – then program the system to close the shades when you want to keep the sun out, or simply desire complete privacy.

# Optimal Energy Management, Privacy, & Mood

- Marvin's shading system allows homeowners the ultimate in control for their exterior shading systems.
- The smart technology allows homeowners to preset the precise shading position for optimal energy management, privacy, and mood.
- "This system provides innovation, style and energy efficiency," said Christine Marvin, Director of Marketing for Marvin Windows & Doors.
- "The combination of proprietary operating technology and shading expertise within Marvin's architecturally detailed exterior casing cavity is a perfect blend of beauty, innovation, quality and performance."

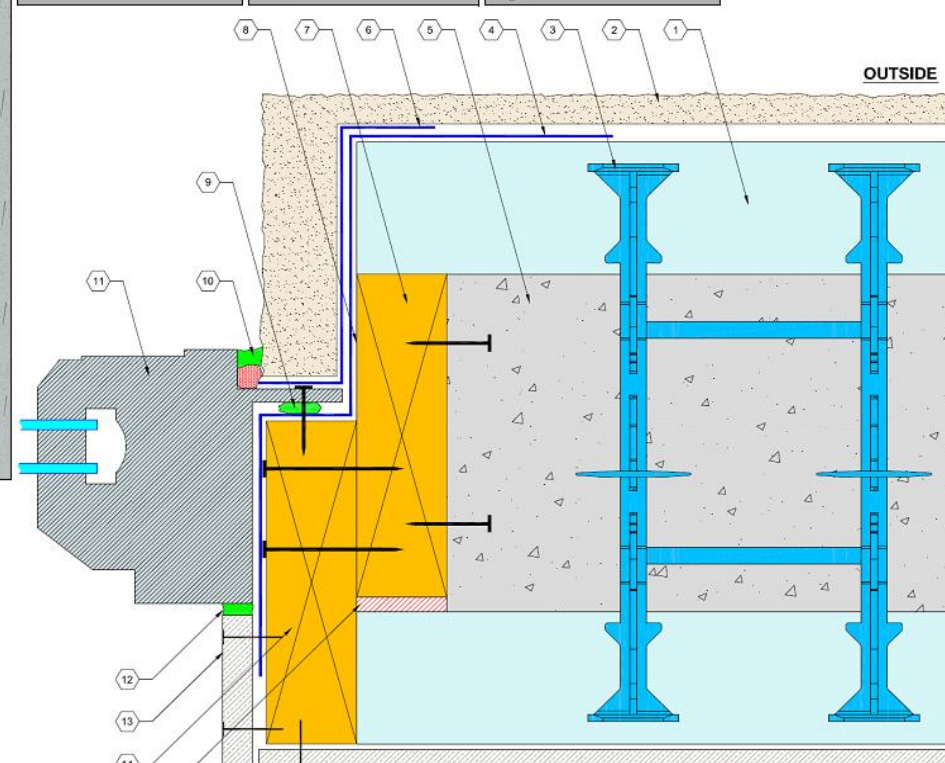
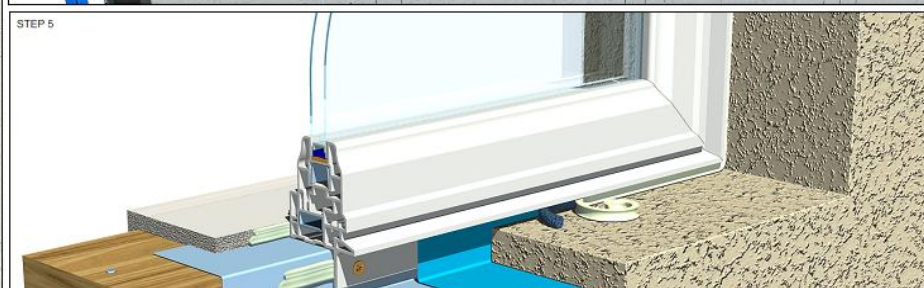
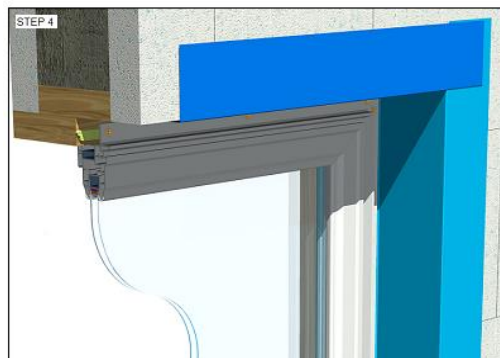
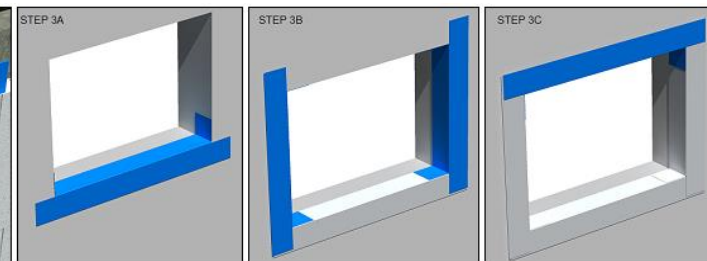
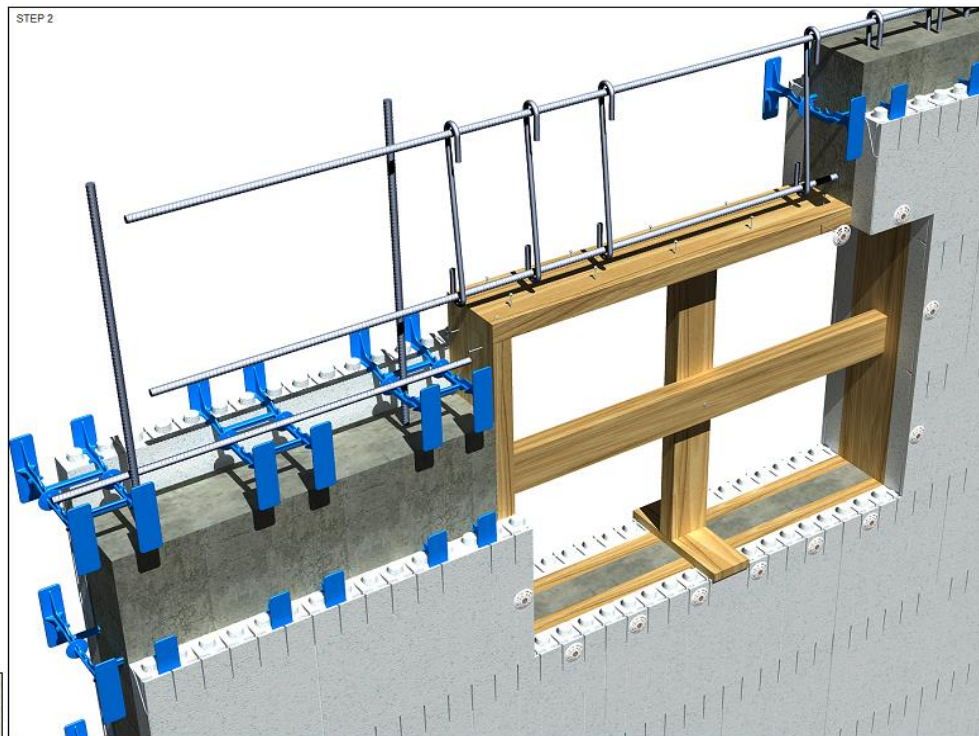
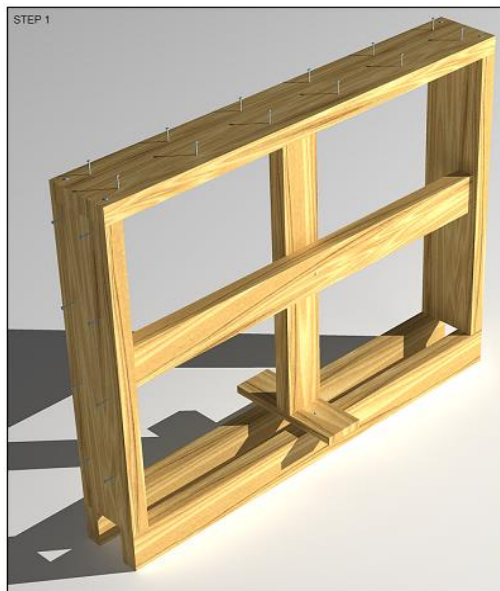
# Shade Compatibility

- Marvin's new shading system is compatible with screened windows. Choose from the currently available options of a retractable louvered screen for solar control and natural ventilation, or the more traditional shade with slats to match your desires for solar control, privacy and improved U-value. Both systems offer an unobstructed view of the Marvin product on the interior, as well as helping to protect the home and furnishings from UV damage when drawn.
- The shading system is compatible with Marvin sliding and swinging windows, including the Ultimate Glider, Ultimate Double Hung, Direct Glaze, Hopper window and Ultimate Picture window, the latter of which is available in sizes as large as 40" wide by 96" tall.

# Exterior Shade Features & Benefits

- Marvin's exterior shading solution includes features and benefits such as:
  - Fully integrated into window – not an add-on
  - Available with Marvin exterior clad casing selections
  - Easy, fully programmable operation.
  - Offers superior control of solar heat gain
  - Shading system is offered in 19 colors to match all standard Marvin clad colors. Slats or louvers are finished in durable Kynar® finish.
  - Shades can easily be replaced by homeowners with exterior access
  - Made in USA – faster delivery than European products
  - Increased occupant comfort through solar heat gain control and additional insulating properties
  - Low-voltage, remarkably quiet integrated motor
  - Self-correcting tracks ensure shades are always in alignment
  - Minimum jamb depths of 6 3/16" for most products
  - An industry-first thermal performance certification pending from PassivHaus Institute and Passive House Institute U.S.

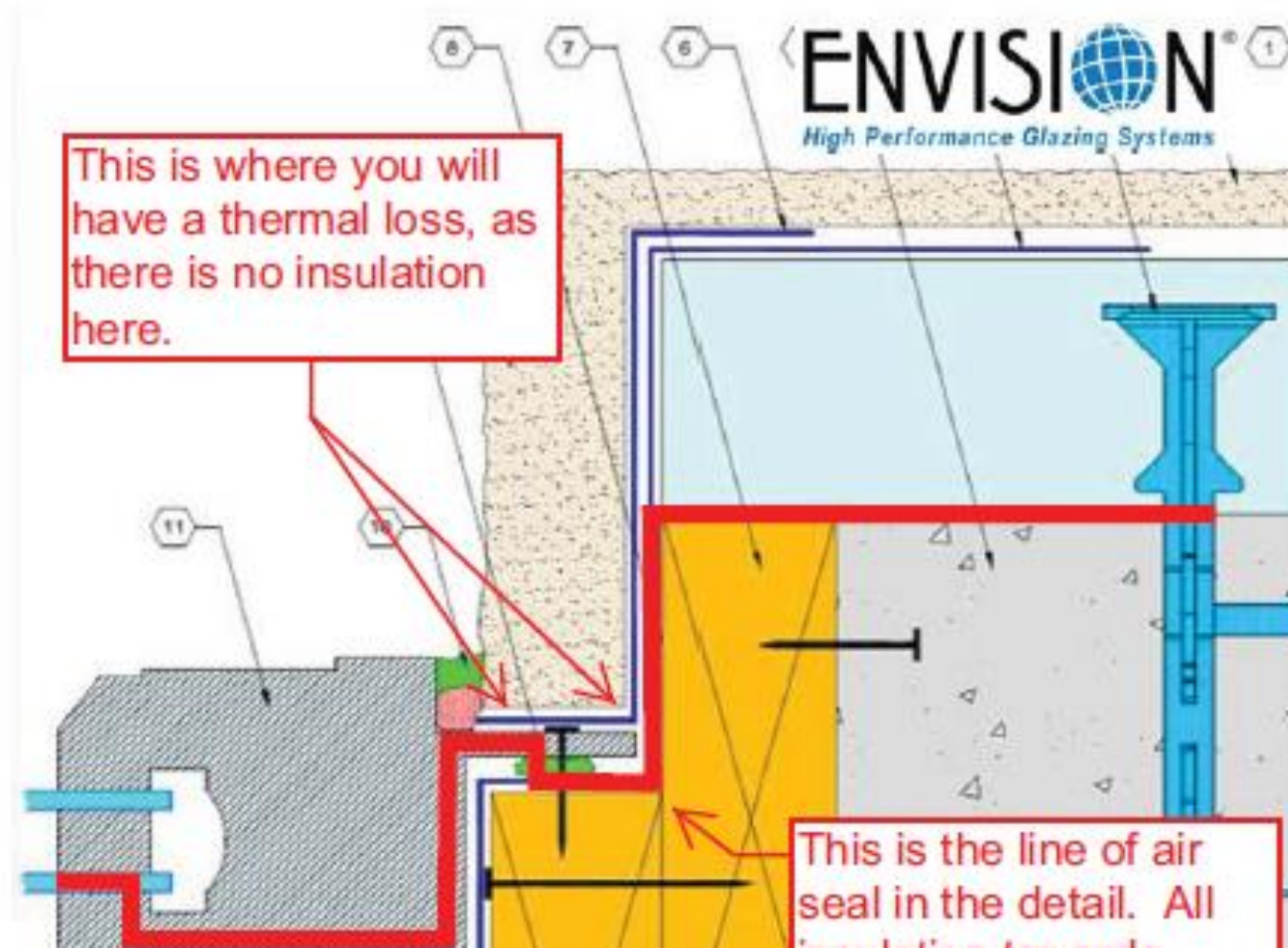
# Quad-Lock Internal Window Buck



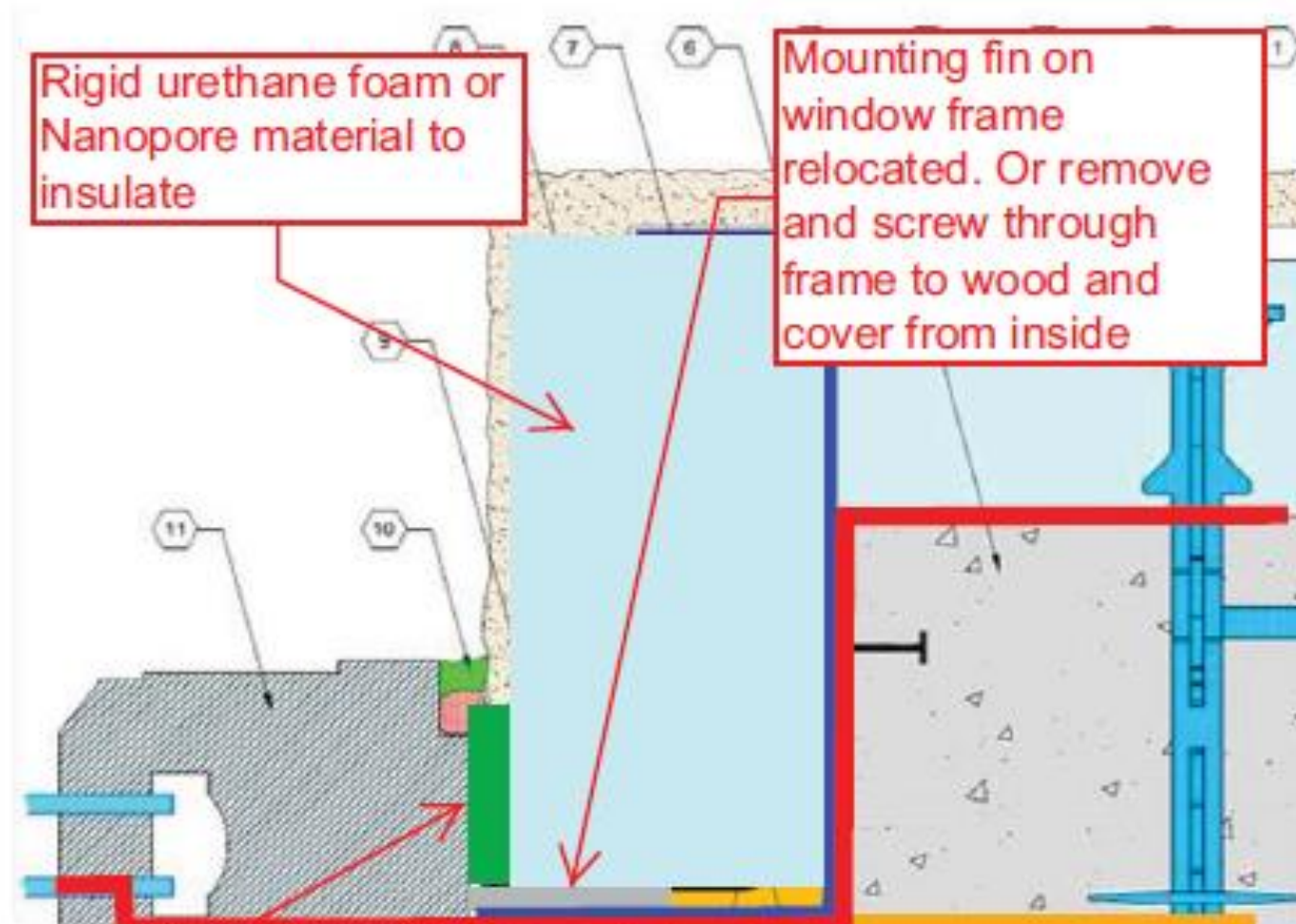
# **Improved Rigid Urethane Foam Installation for ICF Windows**

- A similar though smaller wood block with more foam system (that was anchored to the concrete core) could be used to attach to the window. The slot in the bottom section of the internal buck is used to insure that a good concrete fill is achieved during pouring.
- In addition to the window buck, each of the steps for installation are listed (which would be similar for the R-43 ICF configuration). However, we will use 3” rigid urethane foam cut to size to insulate the core concrete before the window installation in order to eliminate the thermal break created by the pressure treated wood blocking.

# Areas of Improvement For Quad-Lock Window Installation

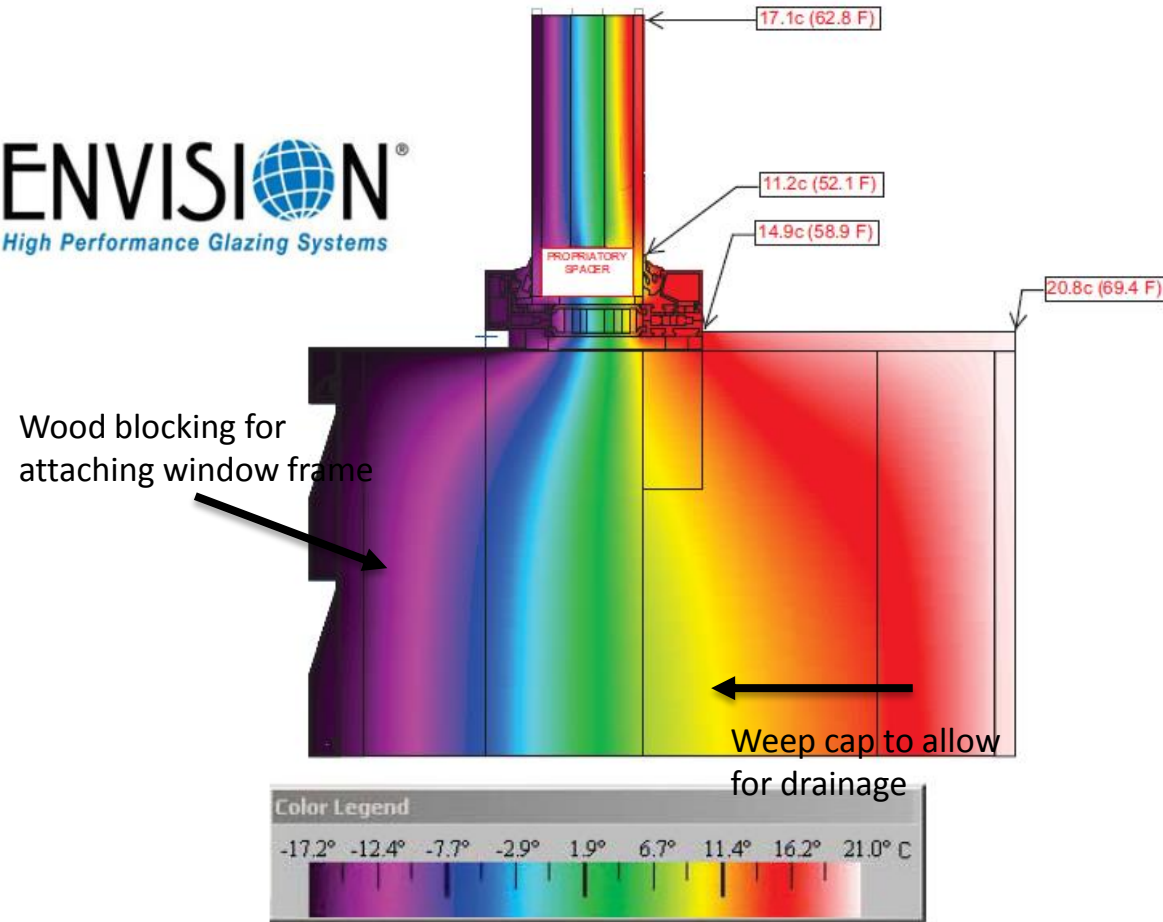


# Improvements Made For Quad-Lock Window Installation



# LBNL Therm 7 Infrared Image of ICF Foam Installation

ENVISION®  
High Performance Glazing Systems



# Hammer & Hand Doors

- Passive wood entry doors made in the US lead the industry in energy efficiency.
- Provide an  $R_{pi}$ -14 via a 3.5” fir wood and EPS foam insulated door.
- Includes a 5 point locking system and comes with a custom door jam to insure air-tight seal and provide added security.

# Flush View of Passive Wood Door



# Hammer & Hand Entry Door Production



# Quality Entry Door Design & Production

- Vacuum clamping bag used in lamination of Passive House door
- Door jamb of custom Passive House door features in-kerf weatherstripping
- Five point interlocking hardware
- The use of polyiso insulation materials could boost thermal insulation performance to as high as R-12 for 3” doors.
- Fiberglass, which has five times the insulation value of wood, can increase the R-value to about R-40 for two inches of VIP material.

# **Advantages of Fiberglass Entry Doors**

- Less expensive than wood
- Lowest maintenance
- Resists denting and scratching
- Offers wood grain and smooth finish look
- Won't rot, deteriorate or rust
- Energy efficient
- Can be painted or stained
- Won't warp, bow or twist
- Five times the insulation value of wood
- Secure

# Insulated Exterior Doors & VIP Technology

- Development of porous solids using nanotechnology provide an opportunity to vastly increase the thermal resistance of exterior doors.
- For a 3” door, thermal insulation can be increased to as high as R-18 using a state-of-the-art **NanoPore™** VIP material.
- Though the R-value of the VIP material can range as high as R-80 for two inches of insulation board, the thermal bridging of the wood reduces the total R-value of the finished door.

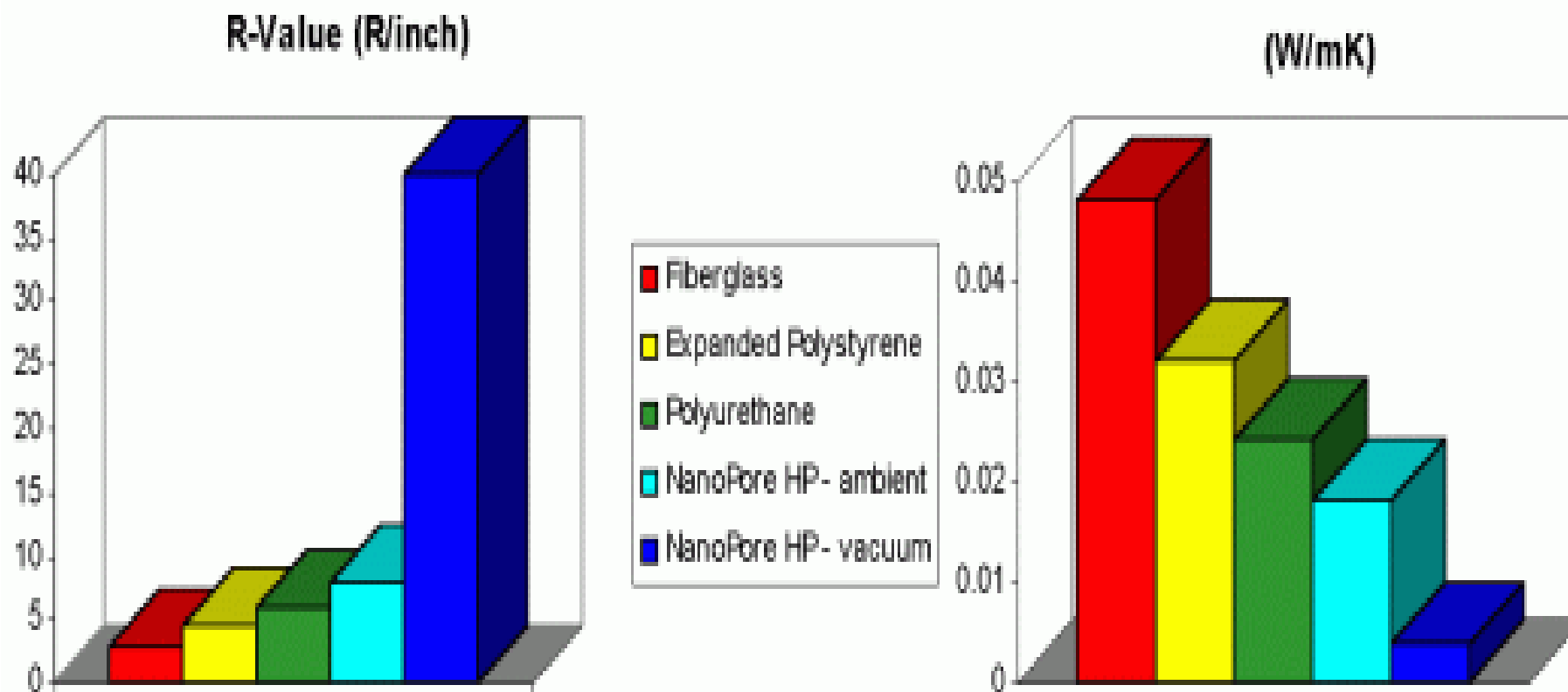
# VIP (R-40/inch) Insulation

- **NanoPore™** thermal insulation is a porous solid that is prepared by one of several processes which yield both low density and small pores.
- Its chemical composition is silica, titania and/or carbon in a 3-D, highly branched network of primary particles (2-20 nm) which aggregate into larger (nm to mm) particles.
- The material has pore sizes ranging from 10-100 nm. It is this nano-scale porosity that gives NanoPore™ its excellent thermal performance.

# Vacuum Insulation Panel

- Because of its unique pore structure, NanoPore™ Thermal Insulation can provide thermal performance unequalled by conventional insulation materials.
- In the form of a vacuum insulation panel ([VIP](#)), NanoPore™ Thermal Insulation can have thermal resistance values as high as R40/inch - 7-8x greater than conventional foam insulation materials.
- A comparison of the thermal performance of NanoPore™ Thermal Insulation versus conventional insulation materials is listed below.

# R-40 VIP Insulation



# Glazing Layers/Panes

- One of the shortcomings of glass is its relatively poor insulating qualities.
- As illustrated above, multiple panes of glass with air or gas filled gaps in between improve the insulating value considerably.
- Relative to all other glazing options, clear single glazing allows the highest transfer of solar energy while permitting the highest daylight transmission.

# The Knudsen Effect

- Due to the unique nano-structure of VIP products, its conductivity can actually be lower than air at the same pressure.
- Its superior insulation characteristics are due to the unique shape and small size of its large number of pores.
- Gas molecules within the matrix experience what is known as the Knudsen effect, which virtually eliminates exchange of energy in the gas, effectively eliminating convection and lowering overall thermal conductivity.

# Solid Phase Conduction

- Solid phase conduction is low due to the materials low density and high surface area, and NanoPore™'s proprietary blend of infra-red opacifiers greatly reduce radiant heat transfer.
- NanoPore™ Insulation may be used over a wide temperature range from below cryogenic ( $<-196\text{ }^{\circ}\text{C}$ ) to high temperatures ( $>800\text{ }^{\circ}\text{C}$ ).

# NanoPore™ Thermal Insulation Products

- The standard thermal insulation product is NanoPore™ HP-150.
- It can be used at temperatures up to 300°C.
- For use with higher temperatures NanoPore produces a special high temperature insulation, NanoPore™ HT-170 for use up to 800°C and above in some cases.
- For applications with highly specific performance requirements, custom grades of NanoPore™ Thermal Insulation can be provided to meet a project's special needs.

# Semi-rigid Insulation Boards

- NanoPore™ thermal insulation begins as a proprietary blend of nanoporous powders which are pressed into semi-rigid boards.
- The boards are then cut to size and shrink-wrapped for ease of handling.
- For some applications these boards are used directly, but in most cases they are processed into vacuum insulation panels, either by NanoPore or by the end user.
- End users may purchase these boards as VIP inserts.

# Vacuum Insulation Panel

- To make a VIP, the inserts are encased in a metalized plastic barrier film and then sealed under vacuum.
- Various barrier materials may be employed to provide the desired performance depending upon the temperature, size, and desired lifetime.
- The completed product is a vacuum insulation panel ([VIP](#)).

# Temperature Range

- A standard VIP can operate in a temperature range from below -330°F (<-200°C) to 250°F (120°C), the maximum continuous working temperature of the barrier film.
- For higher temperature applications, custom vacuum enclosures, made from metal or another impermeable skin, may be used to house the core material.

# Thermal Break

- Vacuum insulation panels (VIPs) may be ideal for providing state-of-the-art thermal breaks for hybrid window frames and exterior doors.
- Depending on cost, VIPs could also be used to install high performance windows.
- These approaches could potentially result in producing frames and installing windows without affecting COG U-values, providing unprecedented energy efficiency.

# Polyisocyanurate (Polyiso) Insulation Materials

- Polyisocyanurate or polyiso is a thermosetting type of plastic, closed-cell foam that contains a low-conductivity, hydrochlorofluorocarbon-free gas in its cells. The high thermal resistance of the gas gives polyisocyanurate insulation materials an R-value ranging from R-5.6 to R-8 per inch.
- Polyisocyanurate insulation is available as a liquid, sprayed foam, and rigid foam board. It can also be made into laminated insulation panels with a variety of facings. Foamed-in-place applications of polyisocyanurate insulation are usually cheaper than installing foam boards, and perform better because the liquid foam molds itself to all of the surfaces.

# Thermal Drift

- Over time, the R-value of polyisocyanurate insulation can drop as some of the low-conductivity gas escapes and air replaces it - a phenomenon is known as thermal drift. Experimental data indicates that most thermal drift occurs within the first two years after the insulation material is manufactured. For example, if the insulation has an initial R-value of R-9 per inch, it will likely drop to R-7 per inch, then remain unchanged unless the foam is damaged.

# Foil & Plastic facings Can Stabilize R-Value

- Foil and plastic facings on rigid polyisocyanurate foam panels can help stabilize the R-value. Testing suggests that the stabilized R-value of rigid foam with metal foil facings remains unchanged after 10 years.
- Reflective foil, if installed correctly and facing an open air space, can also act as a radiant barrier. Depending upon the size and orientation of the air space, this can add another R-2 to the overall thermal resistance. Panels with foil facings have stabilized R-values of R-7.1 to R-8.7 per inch.

# Using SIP Technology for Exterior Doors

- Some manufacturers use polyisocyanurate as the insulating material in structural insulated panels (SIPs). Foam board or liquid foam can be used to manufacture a SIP. Liquid foam can be injected between two wood skins under considerable pressure, and, when hardened, the foam produces a strong bond between the foam and the skins.
- Wall panels made of polyisocyanurate are typically 3.5 inches (89 mm) thick. Ceiling panels are up to 7.5 inches (190 mm) thick. These panels, although more expensive, are more fire and water vapor-diffusion resistant than EPS. They also insulate 30% to 40% better per given thickness.

# Polyurethane Insulation Materials

- Polyurethane is a foam insulation material that contains a low-conductivity gas in its cells. The high thermal resistance of the gas gives polyurethane insulation materials an R-value ranging from R-5.5 to R-6.5 per inch.
- Polyurethane foam insulation is available in closed-cell and open-cell formulas. With closed-cell foam, the high-density cells are closed and filled with a gas that helps the foam expand to fill the spaces around it. Open-cell foam cells are not as dense and are filled with air, which gives the insulation a spongy texture and a lower R-value.

# Thermal Drift

- Like polyiso foam, the R-value of closed-cell polyurethane insulation can drop over time as some of the low-conductivity gas escapes and air replaces it in a phenomenon known as thermal drift.
- Most thermal drift occurs within the first two years after the insulation material is manufactured, after which the R-value remains unchanged unless the foam is damaged.

# Foil & Plastic facings Can Stabilize R-Value

- Foil and plastic facings on rigid polyurethane foam panels can help stabilize the R-value, slowing down thermal drift. Reflective foil, if installed correctly and facing an open air space, can also act as a [radiant barrier](#). Depending upon the size and orientation of the air space, this can add another R-2 to the overall thermal resistance. Panels with foil facings have stabilized R-values of about R-6.5 per inch.
- Polyurethane insulation is available as a liquid sprayed foam and rigid foam board. It can also be made into laminated insulation panels with a variety of facings. Learn more about different [types of insulation](#).

# Sprayed or Foamed-in-place Applications

- Sprayed or foamed-in-place applications of polyurethane insulation are usually cheaper than installing foam boards, and these applications usually perform better because the liquid foam molds itself to all of the surfaces. All closed-cell polyurethane foam insulation made today is produced with a non-HCFC (hydrochlorofluorocarbon) gas as the foaming agent.
- Low-density, open-cell polyurethane foams use air as the blowing agent and about an R-3.6 per inch which doesn't change over time. These foams are similar to conventional polyurethane foams, but are more flexible. Some low-density varieties use carbon dioxide (CO<sub>2</sub>) as the foaming agent.

# Low-density Foams

- Low-density foams are sprayed into open wall cavities and rapidly expand to seal and fill the cavity. Slow expanding foam is also available, which is intended for cavities in existing homes. The liquid foam expands very slowly, reducing the chance of damaging the wall from overexpansion. The foam is water vapor permeable, remains flexible, and is resistant to wicking of moisture. It provides good air sealing and yields about R-3.6 per inch of thickness. It is also fire resistant and won't sustain a flame.

# Using SIP Technology for Exterior Doors

- Soy-based, polyurethane liquid spray-foam products are also available. The cured R-value is about R-3.5 per inch. These products can be applied with the same equipment used for petroleum-based polyurethane foam products.
- Some manufacturers use polyurethane as the insulating material in structural insulated panels (SIPs). Foam board or liquid foam can be used to manufacture a SIP. Liquid foam can be injected between two wood skins under considerable pressure, and, when hardened, the foam produces a strong bond between the foam and the skins. Wall panels made of polyurethane are typically 3.5 inches (89 mm) thick. Ceiling panels are up to 7.5 inches (190 mm) thick. These panels, although more expensive, are more fire and water vapor-diffusion resistant than EPS. They also insulate 30% to 40% better per given thickness.

# Groke Passive House Entry Doors

- Groke Doors range up to 94 mm (abt. 3 inches) thick, constructed of aluminum and dense foam insulation.
- Their highest energy efficiency door has achieved a U-factor of 0.13, e.g., and inverse R-factor of over 8.
- These doors come with an aluminum and foam frame, providing increased security and virtually eliminating air leakage via 3-5 point locking systems.

# Groke Door Construction

